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## TEMPERATURE MEASUREMENTS IN NITROGEN AND NITROGEN—OXYGEN PLASMAS

H. N. Olsen, G. Bedjai, and F. L. Kelly Plasma Sciences Laboratories, Inc.

October 1970

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#### **FOREWORD**

The research reported herein was sponsored by the Arnold Engineering Development Center (AEDC) Air Force Systems Command (AFSC), under Program Element 65701F, Project 4344, Task 434412.

The results of the research were obtained by Plasma Sciences Laboratories, Inc., Tarzana, California. under contract F40600-69-C-0007. The research was performed during the period June 15, 1969 to June 15, 1970, and the manuscript was submitted for publication on July 15, 1970.

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The investigation was conducted under the direction of Dr. H. N. Olsen, serving as Principal Investigator. Mr. G. Bedjai and Mr. F. L. Kelly assisted by performing the experimental work and processing the data as well as with the preparation of the report. The authors wish to acknowledge the help of Mr. D. G. Olsen with the tabulation of data for processing and in the preparation of illustrations for the manuscript.

This technical report has been reviewed and is approved.

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#### ABSTRACT

Using as a source a dc subsonic plasma jet operating in nitrogen and in nitrogen-oxygen mixtures at atmospheric pressure, emission coefficients of the  $N_2(2+)(0,0)$   $\lambda$  3371 neutral molecule band,  $N_2^+(1-)(0,0)$   $\lambda$  3914 ionized molecular band,  $\lambda$  7468 NI atomic line, and the electron continuum have been measured over the temperature range of 3800 to  $10000\,^{\circ}$ K. The emission coefficients of the discrete radiation, calibrated on an absolute scale, were used to calibrate the simultaneously measured electron continuum over the temperature range. Approximate analytical treatments were used to extrapolate the calibrated continuum curves to lower temperatures where discrete radiations can not be observed. The experimental results show considerably higher continuum emission coefficients at low temperature than can be accounted for by any existing theoretical treatments.

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#### NOMENCLATURE

Transition probabilities -  $\sec^{-1}$ Rotational energy constant - cm В Velocity of light - cm-sec c Electronic state energy  $-cm^{-1}$ Ee  $\mathbf{E_r^i}$ Rotational state energy  $-cm^{-1}$ Vibrational state energy  $-cm^{-1}$ E\_ Ionization energy - cm E Ē Gaunt factor Statistical weight g<sub>m</sub>,g\_ J١ Upper state quantum number K' Upper state quantum number K, Calibration constant LS Large spectrograph Boltzmann's constant - erg-deg k Mass of electron - gm m Number density of neutral nitrogen atoms  $-cm^3$ N Number density of neutral nitrogen molecules - cm<sup>3</sup>  $N_{o}$ Number density of ion nitrogen molecules - cm<sup>3</sup>  $N_{\Omega}^{+}$ Number density of electrons - cm<sup>3</sup> N Number density of negative nitrogen ions -  $cm^3$ N Number density of negative oxygen ions - cm<sup>3</sup> 0\_ P Rotational P branch components Rotational Q branch components Q

$Q_{\mathbf{a}}$	Absorption cross-section - cm <sup>5</sup>
$\mathbf{Q_{1}_{D}}$	Negative ion absorption cross-section - ${\rm cm}^5$
q <sub>vv</sub>	Franck-Condon factor
$\mathbf{R}_{\mathbf{e}}$	Electronic moment watt $\frac{1}{2}$ -sec $\frac{1}{2}$ -cm $\frac{3}{2}$
R	Rotational R branch components
$\mathbf{s_{J}^{i}},$	Line strength for rotational components
SS	Small spectrograph
T	Temperature - °K
$\mathbf{U}_{\mathbf{o}}$	Nitrogen atom partition function
${\bf v_2}$	Nitrogen molecule partition function
$\mathbf{U_2^+}$	Nitrogen molecular ion partition function
x, y,	z Coordinates - cm or inches
${f z}$	Effective nuclear charge
$a_{\kappa'}$ $\beta_{\kappa'}$	Alternation factors for even and odd K'
γ	Doubling constant - rotational state
€	Emission coefficient - watt-cm <sup>3</sup> -sr <sup>1</sup> -sec
λ	Wavelength - cm

#### I. INTRODUCTION

The objective of the investigation described in this report was to develop spectral diagnostic methods for pure nitrogen plasmas in the temperature range of 3000°K to 5000°K. This represents a first step in the development of practical tools for rapid spectral diagnostics of supersonic plasma streams such as are employed in Air Force material testing and reentry simulation facilities. Extensions of the methods for applications to air plasmas were initiated toward the end of this program with applications to nitrogen-oxygen mixtures.

In an earlier investigation it was shown that the continuous radiation in seeded nitrogen and air plasmas could be used with the Kramers-Unsöld theory for determination of equilibrium temperatures but the same was not found to be true for the unseeded pure gases. The relative simplicity of detectors for spectrally resolved continua and their potential applications in future rapid scanning diagnostic systems emphasized the need for this investigation of the theoretical and experimental relationship between radiation and temperature in equilibrium plasmas.

The general plan of this investigation was to experimentally establish the relationship between the radiation of four different species of particles, i.e. neutral and ionized molecules, atoms and free electrons, in high temperature, atmospheric pressure, pure nitrogen plasmas where absolute calibrations can be made against analytical treatments based on an equilibrium composition of the gas. The calibrated discrete spectra of the atomic and molecular species can then be used to experimentally calibrate the electron continuum against temperature as the level of temperature in the plasma is successively reduced. At lower temperatures, where the discrete radiations blend into the background continuum, the calibration can proceed only by means of an extrapolation based on an analytical description of the temperature

dependence of the continuum established at the higher temperatures through proper combinations of theory and experiment.

The analytical and experimental methods first established on nitrogen plasmas are then applied to nitrogen-oxygen mixtures used to simulate air plasmas. Here the problems of gas mixing and rate processes involving the NO molecule and the NO<sup>+</sup> molecular ion enter the picture requiring more extensive experimentation on pure air plasmas for more complete descriptions.

The apparatus used for producing the controlled laboratory plasmas and for detecting and calibrating the several species of radiation are described in Section II. Section III treats the analytical computations of the normalized emission coefficient for each of the species of radiation considered. In this section the wavelength increments of the molecular band systems are defined as used throughout and corrections of some errors made in an earlier treatment<sup>2</sup> of these systems have been included. The detailed experimental procedures and results are given in Section IV. In Section V the experimental and theoretical significance of the results are discussed with conclusions and recommendations given in Section VI.

#### II. APPARATUS

Three different sources were used to produce the nitrogen, nitrogen-oxygen and air plasmas used in this investigation, i.e., a dc plasma jet, a dc free-burning arc and an rf induction torch. The general arrangement of these three sources with respect to the radiation detection and calibration systems is shown schematically in Fig. 1. Detailed descriptions of the apparatus and experimental methods are given in the following sub-sections.

#### A. PLASMA JET

The plasma jet, developed in an earlier phase of this long range diagnostics program and which is described in detail in Ref. 3, was designed to permit changes in its internal configuration. Two configurations, i.e., high (I) and low (III) temperature, were used in this program to produce temperatures ranging from 3000 to 6000°K and 5000 to 10000°K respectively. The jet head was designed to operate with or without an observation section and quench chamber. In cases where the quench was used the exit gas was first cooled by means of a nested tube heat exchanger before being vented. No attempt was made to determine the quantity of heat transferred to the quench chamber or that which remained in the vented gases. Only the losses in the jet head were determined calorimetrically.

Because of the tungsten cathode only nonreacting gases such as argon or pure nitrogen can be used as the primary gas. A range of temperatures in the plasma can be obtained by controlling the current, gas flow, and position of observation. A very sizeable reduction in the jet temperature can be effected by adding down stream cooling gas through an opening provided in the lower constrictor section. By means of the configuration changes and down stream gas injection, temperatures ranging from 3000°K to 10000°K could be established in 1 atm pressure plasmas in pure nitrogen and nitrogen-oxygen mixtures.

The latter could be obtained by adding oxygen as the down stream gas to a nitrogen plasma. Because of the tungsten cathode pure air could not be run with this jet.

#### B. FREE-BURNING ARC

The arc burned freely in pure nitrogen at 1.1 atmosphere pressure between a 1/8 inch dia, 1% thoriated tungsten cathode and a plane copper anode in a vacuum tight water cooled chamber. The electrodes were also water cooled and separated by  $\frac{1}{4}$  inch and the current was adjusted to 210 amp with an operating potential of 29.1 volts. Again, because of the tungsten cathode, only pure nitrogen could be used.

#### C. RF INDUCTION TORCH

An rf induction torch similar to that described by Olsen, Eckert and Kelly<sup>2</sup> has been used here to produce equilibrium plasmas in nitrogen and air. The plasma was electromagnetically induced in a swirling stream of gas flowing at a rate of 30 scfh within a 4 inch dia air cooled transparent quartz tube. Typical operation with nitrogen was 60kw plate power at 30 scfh; with air the plate power was 50kw at 25 scfh. The specially designed 100kw power source developed at PSL was used for generating these plasmas.

#### D. SPECTROGRAPHS

Two plane grating spectrographs have been used throughout this program either individually or in combination as shown in Fig. 1. For high resolution work involving separate quartet or sextet groupings of the nitrogen band systems the 1 meter reflection optics instrument (LS) having a first order dispersion of 8.3 Å/mm was used. This instrument was equipped for either photoelectric or photographic readout. Typical photographed spectra are shown in Fig. 2.

To permit simultaneous measurements of two species of radiation the  $\frac{1}{4}$  meter grating spectrograph (SS) developed as part of the spectral

probe system for seeded plasma diagnostics and described in Ref. 1 was placed in the same optical path as the large instrument by means of a half-silvered mirror as shown in Fig. 1. With a dispersion of  $55\text{\AA}/\text{mm}$  only the continuum, well separated spectral lines, or broad increments of the band systems can be recorded with photoelectric readout on this instrument. The optical speed is f/10.5 as compared with f/9 for the 1 meter spectrograph. The glass optics posed no problem since all radiation detected with the small spectrograph was at wavelengths  $\lambda > 3800 \text{ Å}$ .

Interchangeable entrance and exit slits, and photomultiplier housings were provided for both spectrographs. Blue sensitive 1P28 photomultipliers were used throughout the investigations. Widths of 50  $\mu$  and 500  $\mu$  were used interchangeably as entrance and exit slits. In the exit position the broad slit represents a 28 Å increment of the dispersed spectrum of the small spectrograph at  $\lambda$  3920 Å and a 3.9 Å increment for the large instrument at the same wavelength.

#### E. DUAL-SIGNAL RECORDING SYSTEM

In order to eliminate the question of changes in source conditions during the time required to record a full radial profile, the data recording system was designed to permit simultaneous recording of two radial profiles. With this system the radiation from any one of the three sources or from the calibration carbon arc was directed by means of a plane mirror through an aperture and focusing lens and onto a half-silvered mirror which separated the beam into two parts of nearly equal intensity. These two beams were directed to the entrance slits of the two spectrographs as shown on the schematic diagram of Fig. 1.

The amplitude (intensity) signals taken from each of the photo-multipliers were fed to separate impedance matching operational amplifiers and then into a chopper circuit. The chopper consisted of a sealed relay driven by a solid state timing circuit with variable on-off time periods. This chopper alternately connected the two intensity signals  $(y_1 \text{ or } y_2)$  to the y input of the x-y recorder while the radial

position signal from the transport table served as the x-axis signal of the recorder. To permit simultaneous recording of signals with large differences in amplitude, the photomultiplier voltages must be independently adjusted. This was accomplished by using a common regulated high voltage supply and separate voltage divider networks as shown in Fig. 3.

The simultaneous recording of two species of radiation from a plasma with two spectrographs and detectors requires that the separate optical systems be in precise alignment. To achieve this an autocollimating method was used on each of the two spectrographs in common with the half-silvered mirror, the focusing lens, and right-angle mirror. The photomultiplier on each spectrograph was replaced by a tungsten lamp so that an image of the entrance slit, illuminated in monochromatic light, was formed at the point where the source would normally be located. The images of the two spectrograph slits, formed in this manner at different wavelengths in the visible spectrum, were observed with a small instrument telescope and were made to coincide on the cross-hair by rotating, tilting and translating the halfsilvered mirror (beam splitter). When optical coincidence was accomplished, the system was in proper alignment as indicated by identical recorded shapes of a common intensity profile. The progressive reduction of slit widths and lengths increased the alignment precision.

The shapes of the continuum and atomic line profiles of the conically shaped, free-burning, argon arc were observed as simultaneous pairs on the x-y recorder by means of the chopping method to demonstrate proper alignment. Figures 4 and 5 show experimental profiles recorded in this manner. The separation of the carbon arc traces corresponds to the difference in spectrograph slit widths. When the peak amplitudes of the two signals are made to be the same by adjusting photomultiplier voltages, and the spectrographs are set at the same wavelengths with equivalent slit widths the result is a single trace of y vs x under chopping conditions as shown for example in Fig. 4. When the two curves have different amplitudes or shapes, the two traces are defined

by the tops and bottoms of the chopping pulses generated by the alternating amplitudes as shown in Fig. 5.

#### F. ABSOLUTE INTENSITY CALIBRATIONS

Absolute spectral intensities have been measured throughout this investigation by comparison with the positive crater of the low current carbon arc. The intensity versus wavelength for the carbon crater was determined, according to Null and Lozier, for a temperature of 3800°K and emissivity of 98%. The transport table shown in Fig. 1 was designed so that the carbon calibration arc could replace the experimental plasma at the focal position of the same optical system so that on-the-spot calibrations could be made with each measurement.

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#### III. ANALYTICAL METHODS

The quantitative nature of the diagnostic methods employed requires theoretical computations of emission coefficients as a function of temperature for equilibrium nitrogen and nitrogen—oxygen plasmas. Each species of radiation is discussed separately in the sub-sections which follow. The particle number densities and partition functions used in the computations were taken from the unseeded plasma compositions given in Ref. 1 as listed in Table I.

A. 
$$N_2$$
 (2+)(0,0),  $\lambda$  3371 Å,  $C^3 \pi_u - B^3 \pi_g$ 

The detailed structure of this band is shown in the photographed spectrum of Fig. 2. Because of the triplet nature of the electronic state from which the system arises, there are three subbands,  $3\pi_0 + 3\pi_0$ ,  $3\pi_1 + 3\pi_1$ , and  $3\pi_2 + 3\pi_2$  with a strong R(J'+J'-1), a strong  $P(J' \rightarrow J' + 1)$  and a weak  $Q(J' \rightarrow J')$  branch; the latter may be completely neglected. The two strong branches produce characteristic triplets in the rotational structure which are grouped in sextets as observed in the spectrum of Fig. 2. Throughout this description the J' subscript used to identify a particular sextet is taken as the rotational quantum number of the upper energy level of the R branch component of the third  $(3\pi_2 + 3\pi_2)$  sublevel. Such a reference was chosen because this component denoted as R<sub>J</sub><sup>2</sup>, is located nearly in the center of the sextet and its wavelength is taken as the center wavelength,  $\lambda_{a}$ , of the sextet. According to this identification system the individual components of the sextet reading toward longer wavelengths are designated  $R_{J'+2}^0$ ,  $R_{J'+1}^1$ ,  $R_{J'}^2$ ,  $P_{J'+19}^0$ ,  $P_{J'+18}^1$ ,  $P_{J'+17}^2$ . The sextet centered about the wavelength of the  ${ t R}_{{\mathcal J}^{f 1}}^{f 2}$  rotational line will generally be referred to throughout this report as the "R, component" of the band.

The absolute emission coefficient for any single rotational element of a vibrational band of a given electronic transition can

be expressed as

$$\epsilon_{\mathbf{J}'}^{\mathbf{i}} = c \frac{N_2}{\overline{U}_0} \exp \left[ -(\mathbf{E}_{\mathbf{e}} + \mathbf{E}_{\mathbf{v}}) / \mathbf{k} \mathbf{T} \right] \mathbf{S}_{\mathbf{J}'}^{\mathbf{i}} \exp \left[ -\mathbf{E}_{\mathbf{r}}^{\mathbf{i}} (\mathbf{J}') / \mathbf{k} \mathbf{T} \right]$$
 (1)

The subscript J! is used to identify either the individual rotational component or a particular grouping of components which are individually identified by the superscript i. The electronic, vibrational, and rotational upper state energies are given by  $E_e$ ,  $E_v$  and  $E_r^i$  (J') respectively. The constant is given by

$$C = \frac{16\pi^3 c}{3\lambda^4} R_e^2 q_{vv}$$

where c is the velocity of light,  $\lambda$  the wavelength of the transition,  $R_e$  the electronic moment,  $q_{vv}$  is the Franck-Condon factor. The  $S_J^i$  in Eq. (1) is the relative strength factor for the  $i^{th}$  rotational component of the sextet. The number densities N and partition functions U are taken from Table I.

For purposes of computation, the emission coefficient for each component of a sextet is denoted by  $\epsilon_{J}^{i}$ , where i=1, 2 ...6 for the components in order of increasing wavelengths. The emission coefficient for the total sextet is then

$$\epsilon_{J}$$
, =  $\sum_{i=1}^{6}$   $\epsilon_{J}^{i}$ .

Using the wave number tabulations of Coster, et. al.<sup>5</sup> and a mercury reference spectrum, the  $\epsilon_{27}$  and  $\epsilon_{28}$  sextets can be easily recognized as surrounding the Hg I  $\lambda$ 3341 line as shown on Fig. 2 and from this the R<sub>38</sub> component is identified by counting to the left (shorter wavelengths).

In order to compute the emission coefficients for all components of this band it is first necessary to express the relative line strengths in terms of the upper rotational quantum number of the  $R_{J'}^2$  component. From the wave number tabulation of Ref. 5 it is found that upper level quantum numbers of J'+2, J'+1, J', J'+19, J'+18 and J'+17 correspond with  $i=1, 2, \ldots 6$  respectively. With these quantum numbers the respective line strengths, according to Budo , which hold for J'>10, are

$$S_{J'}^{1} = \frac{J' (J'+2) (2J'+5)}{(J'+1) (2J'+3)} \qquad S_{J'}^{4} = \frac{(J'+18) (J'+20) (2J'+41)}{(J'+19) (2J'+39)}$$

$$S_{J'}^{2} = \frac{(J') (J'+2)^{2}}{(J'+1)^{3}} \qquad S_{J'}^{5} = \frac{(J'+18)^{2} (J'+20)^{2}}{(J'+19)^{3}}$$

$$S_{J'}^{5} = \frac{J' (J'+2) (2J'-1)}{(J'+1) (2J'+1)} \qquad S_{J'}^{6} = \frac{(J'+18) (J'+20) (2J'+35)}{(J'+19) (2J'+37)} .$$
(2)

The corresponding rotational energy levels are

$$\begin{bmatrix}
E_{\mathbf{r}}^{1} & (J') = B_{\mathbf{v}}(J'+2) & (J'+3) & E_{\mathbf{r}}^{k} & (J') = B_{\mathbf{v}} & (J,+19) & (J'+20) \\
E_{\mathbf{r}}^{2} & (J') = B_{\mathbf{v}}(J'+1) & (J'+2) & E_{\mathbf{r}}^{5} & (J') = B_{\mathbf{v}} & (J'+18) & (J'+19) \\
E_{\mathbf{r}}^{3} & (J') = B_{\mathbf{v}}(J') & (J'+1) & E_{\mathbf{r}}^{6} & (J') = B_{\mathbf{v}} & (J'+17) & (J'+18)
\end{bmatrix} (3)$$

where  $B_v = B_e - \infty_e$   $(v + \frac{1}{2})$  with  $B_e = 1.8259 \text{cm}^{-1}$ ,  $\infty_e = .0197 \text{cm}^{-1}$ ,  $E_e = 89,147 \text{cm}^{-1}$  and  $E_{v=0} = 1017 \text{cm}^{-1}$  for the C  $^3 \pi$  state.

Since the R<sub>e</sub><sup>2</sup>q<sub>vv</sub> factor in the calibration constant for the emission coefficient is generally not known or is to be determined experimentally by comparison of computed and measured emission coefficients at the temperature of the peak value, it is only practical to compute the normalized emission coefficients,  $\epsilon_{J^i}^{*i}$ , according to Eq. (1) with this factor set to unity. Normalized emission coefficients of each component and of the total sextet have been computed earlier (Ref. 2) using partition functions given by Drellishak, et. al. for pure nitrogen and number densities for air computed by Hilsenrath, et. al. In the original computations reported in Ref. 2 some errors were made which have been corrected here and the results are presented in Tables IIA and IIB

B. 
$$N_2^+$$
 (1-) (0,0),  $\lambda$  3914 Å,  $B^2 \sum_{u}^+ X^2 \sum_{\sigma}^+$ 

In the case of  $\sum$  transitions the separation of the two sublevels with  $J' = K' + \frac{1}{2}$  and  $J' = K' - \frac{1}{2}$  gives rise to a quartet structure with two R and two P branch components and no Q branch. Because of the small separation of the sublevels the two subbands are not resolved in the spectrum of Fig. 2.

Following the same procedure as above for the neutral molecule band systems, the quartet components are identified by  $\epsilon_{K'}^i$ , where i=1, 2, 3, 4, correspond with  $R_{K'}^1 + \frac{1}{2}$ ,  $R_{K'}^2 - \frac{1}{2}$ ,  $P_{K'}^1 + 27 + \frac{1}{2}$ ,  $P_{K'}^2 + 27 - \frac{1}{2}$ . As is conventional for components of  $\sum - \sum$  transitions, the K' quantum number is used and is here defined as the upper state rotational quantum number associated with the  $R_{K'}^2 - \frac{1}{2}$  component having wavelength  $\lambda_0$  taken as the center value for the quartet. The emission coefficient for the total quartet is

$$\epsilon_{K'} = \sum_{i=1}^{4} \epsilon_{K'}^{i}$$

The H<sub>g</sub> $\lambda$ 3906 I line can be used to identify the R<sub>6</sub> quartet at  $\lambda$ 3905.8 Å as shown on Fig. 2.

According to Mulliken the component line strengths can be written in terms of the K' quantum number of the upper state as

$$s_{K'}^{1} = \frac{(2K'+1)^{2} - 1}{2(2K'+1)} \approx_{K'} \qquad s_{K'}^{3} = \frac{(2K'+53)^{2} - 1}{2(2K'+53)} \beta_{K'}$$

$$s_{K'}^{2} = \frac{(2K'-1)^{2} - 1}{2(2K'-1)} \approx_{K'} \qquad s_{K'}^{4} = \frac{(2K'+51)^{2} - 1}{2(2K'+51)} \beta_{K'}$$
(4)

where 
$$\underset{K'}{\thickapprox} = \begin{cases} 1 \text{ for } K' \text{ odd} \\ \frac{1}{2} \text{ for } K' \text{ even} \end{cases}$$
  $\underset{K'}{\mathrel{\mathrel{\begin{subarray}{c} K' \\ 1 \text{ for } K' \text{ even} \end{subarray}}} \qquad \underset{K'}{\mathrel{\begin{subarray}{c} \frac{1}{2} \text{ for } K' \text{ odd} \\ 1 \text{ for } K' \text{ even} \end{subarray}}}$ 

are the familiar intensity alternation factors which are characteristic of this band system.

The rotational energy levels are expressed in terms of the upper level quantum number K' as

$$E_{\mathbf{r}}^{1}(K') = B_{0}(K')(K'+1) - D_{0}(K')^{2}(K'+1)^{2} + \frac{\mathbf{r}^{2}K'}{2}$$

$$E_{\mathbf{r}}^{2}(K') = B_{0}(K')(K'+1) - D_{0}(K')^{2}(K'+1)^{2} - \frac{\mathbf{r}^{2}K'}{2}$$

$$E_{\mathbf{r}}^{3}(K') = B_{0}(K'+25)(K'+26) - D_{0}(K'+25)^{2}(K'+26)^{2} + \frac{\mathbf{r}^{2}(K'+25)}{2}$$

$$E_{\mathbf{r}}^{4}(K') = B_{0}(K'+25)(K'+26) - D_{0}(K'+25)^{2}(K'+26)^{2} - \frac{\mathbf{r}^{2}(K'+25)}{2}$$
where  $B_{0} = 2.07325 \text{ cm}^{-1}$ ,  $D_{0} = 5.895 \text{ x} \cdot 10^{-6} \text{ cm}^{-1}$  and  $\mathbf{r}^{2} = .002 \text{ cm}^{-1}$ .

Using Eqs. (4) and (5) in Eq. (1) with E = 25,462 cm<sup>-1</sup> and E = 1204 cm<sup>-1</sup> the component and total emission coefficients for K' ranging from 1 to 22 were previously computed and reported in Ref. 2. As was the case of the neutral band system a number of errors were made in the original computations which have been corrected here with the results given in Tables III A and III B. The intensity alternations, which were omitted in the previous computations are clearly seen in these results. These alternations are also observed in the spectrum of Fig. 2. In order to adjust the normalized emission coefficients of Tables II and III to other composition data the required number densities and partition functions of neutral and ionized molecules are given in Table I for both nitrogen and air plasma. For completeness sake the corresponding atom, electron and negative ion number densities are also included.

An observed characteristic of this molecular ion band is the grouping of the first 26 P branch doublets  $(P_{K'}^1$  and  $P_{K'}^2$  for  $25 \ge K' \ge 0)$  in the region of the band head where there are no R branch components. This group, which is indicated by the bracketed region labeled  $\text{EH}\Delta_1$  in Fig. 2 will be referred to throughout this report as the "ion band head increment". The long wavelength edge of the 3.9 Å increment  $(\text{BH}\Delta_1)$  is defined by the  $\lambda 3914.33$   $(P_{14})$ , component and the short wavelength edge falls between the  $\lambda 3909.71$   $(R_1)$  and  $\lambda 3910.43$   $(P_{25})$  components. In a similar manner a 28 Å increment  $(\text{BH}\Delta_2)$  is defined by the  $P_{14}$  and the  $\lambda 3885.3$   $(R_{22})$  component and is also indicated in Fig. 2. The actual wavelength interval is 28.5 Å but will be referred to throughout as the 28 Å increment.

The emission coefficient for the 3.9 Å band head increment has been computed as follows

$$\epsilon_{\text{BH}\Delta_{1}} = c \frac{N_{2}^{+}}{U_{2}^{+}} \exp \left(-\frac{E_{e}^{+E}v}{kT}\right) \sum_{K'=0}^{25} \left\{ \frac{2(K'+1)}{\lambda_{K'}^{+}} \left[1 - \frac{1}{(2K'+1)(2K'+3)}\right] \beta_{K'}^{-} \right\}$$

$$\exp \left[-B_0K' \left(K'+1\right)/kT\right]$$
 (6)

where all quantities are as previously defined. The component wavelengths were taken from Ref. 5. Numerical values of this emission coefficient are tabulated in Ref. 1 for air and nitrogen with  $R_{\rm e}^2$  q = 1.36 x 10<sup>-36</sup> and E = 0. These results have been corrected for the zero point energy of the v = 0 vibration state which is 1204 cm<sup>-1</sup> rather than zero as was erroneously assumed. The corrected normalized emission coefficients for the 3.9 Å ion band head increment are given in Table IV.

The normalized emission coefficient for the 28 Å increment is obtained by adding the  $R_{K'}$  components for K=1 through 22 to the P branch components of the 3.9Å increment such that

$$\epsilon_{\text{BH}\Delta_2} = \epsilon_{\text{BH}\Delta_1} + \sum_{K'=1}^{22} \epsilon_{K'}^{R} \tag{7}$$

The normalized emission coefficients for the  $28 \stackrel{\circ}{A}$  increment are also listed in Table IV. For purposes of internal consistency in this report all emission coefficients are referred to the number densities given in Table I.

### c. Atomic line, $\lambda$ 7468 NI

This discrete spectral line represents transitions between the 3p <sup>1</sup>S° upper and the 3s <sup>1</sup>P lower energy levels of the neutral nitrogen atom. Emission coefficients were computed using the number densities and partition functions of Table I and the following equation:

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$$\epsilon_{7468} = C_{\overline{U}_{0}}^{N_{0}} \exp \left(-E_{m}/kT\right)$$

$$c = \frac{hcg_{m}A_{n}^{m}}{\lambda 4 \overline{T}}$$
(8)

with

where h is Planck's constant,  $g_m$  the statistical weight and  $A_n^m$  the spontaneous transition probability for the line of wavelength  $\lambda$  and upper energy level  $E_m$ . The particle number density  $N_0$  and partition function  $U_0$  are for the neutral atom. The normalized emission coefficients, computed for  $A_n^m=1$ , are given in Table IV. The normal temperature for the 1 atm nitrogen plasma is 15,000°K. Just as with the band systems the transition probability can be determined experimentally by comparing the measured peak value for the emission coefficient emitted by an equilibrium source with the peak of the normalized coefficient; such a determination is discussed in the next section.

#### D. CONTINUUM

The source of continuous radiation emitted by a diatomic gas plasma is the free electrons which are retarded by electrostatic interactions with ionized atoms, ionized molecules and screened neutral atom or molecule nuclei (free-free transitions) or which recombine with atomic or molecular ions to form neutrals and attach to neutral atoms to form negative ions (free-bound transitions). Radiative recombinations of atoms can give rise to a molecular continuous emission; however, because of the extremely low probability of such a process relative to non-radiative three body recombinations, this source of continuum may be completely neglected in the 1 atm plasmas treated here. Molecular formation by radiative two-body recombination with two atoms approaching on the potential curve of the ground state is not possible for two like molecules and can be neglected entirely here.

The analytical treatment of the electron continuum is very dependent upon the temperature range under consideration. For example, Morris, et. al. 10 have shown that for nitrogen at 1 atm the free-free

and free-bound radiation of positive ions reacting with electrons can explain the entire observed continuum at temperatures above 15,000°K. At lower temperatures neutral atom-electron interactions become significant. In Ref. 10 it has been shown that for temperatures in the range 8000 to 10000°K in atmospheric pressure nitrogen the observed continuum results almost entirely from free-bound radiation of the negative nitrogen ion formed by electron attachment with neutral atoms. At temperatures below 5000°K where the number of neutral atoms and ionized molecules is low relative to the number of neutral molecules, the main contribution to the continuum is assumed to be the free-free radiation of free electrons interacting with neutral molecules.

Very little quantitative work has been reported on the continuum emitted by nitrogen or air plasmas at temperatures below 8000°K. The absence of reliable quantitative data on radiation cross-sections for the species of radiation involved makes it difficult to analytically describe the continuum at low temperatures. In the following descriptions the best approximate values available in the literature are used to compare at least the relative contributions to the total (spectrally resolved) continuum at equilibrium temperatures below 10,000°K.

In this investigation, where the aim has been to determine equilibrium temperatures from measured emission coefficients in the range of 3000°K to 10,000°K, analytical expressions for the significant sources of continua are used only as guides in extrapolating the measured continuum versus temperature curve below the lower temperature limit of the experimental calibration. In this temperature range only three sources of continua need be considered, i.e., free-free radiation of electrons retarded by positive ions and neutral molecules, free-bound radiation of electrons recombining with positive ions, and free-bound radiation of electrons attaching to neutral atoms. According to Ref. 10, free-free radiation resulting from the retardation of electrons by neutral atoms is assumed to be negligible in comparison with the free-bound radiation produced by the attachment process. With these assumptions

the relative contributions to the continuum at a given wavelength have been computed according to the following expression:

$$\epsilon_{\text{cont.}} = 5.4 \times 10^{46} \text{ Z}^{2}_{\text{g}} \text{ N}_{e}^{2}/\text{T}^{\frac{1}{2}} + 4 \times 10^{23} \text{ exp } (-\text{C}_{2/\lambda_{\text{T}}})/\lambda^{3}$$

$$\times \left[Q_{1_{\text{D}}N_{-}} + \frac{Q_{\text{a}}N_{2}N_{e}}{\lambda^{2}}\right] \text{ (watt-cm}^{-3}-\text{sr}^{-1}-\text{sec})$$
(9)

where Z = effective nuclear charge

 $\bar{g} = gaunt factor$ 

 $C_0 = 1.4388 \text{ (cm-oK)}$ 

 $\lambda$  = wavelength (cm)

Q<sub>1</sub> = cross-section for recombination into 1<sub>D</sub> state of the negative ion, (cm<sup>5</sup>)

 $N_{-1}$  = number density (cm<sup>-3</sup>) of negative nitrogen ions in  $^{1}D$  level

 $N_{\rm c} = {\rm electron\ number\ density\ (cm}^{-3})$ 

 $N_2$  = neutral molecule number density (cm<sup>-3</sup>)

 $Q_a = radiation absorption cross-section for neutral molecules <math>(cm^5)$ .

Bolt 11 has shown that the negative ion number densities can be computed according to the Saha and Boltzmann equations combined in the form

$$\frac{N_0 N_e}{N_-} = 2 (277 \text{mkT})^{3/2} \frac{U_0(T)}{g_-} \exp \left[ (E_{1_D} - E_{\infty}) / \text{kT} \right]$$
 (10)

where  $U_0(T)$  = partition function of atom  $g_-$  = statistical weight of  $^1D$  state of  $N_-$  taken as 5  $E_1^D$  = energy of  $^1D$  state which is 19223 cm $^{-1}$   $E_m$  = ionization energy which is cm $^{-1}$ 

and all other quantities have their usual meanings. In Eq. (10) the number densities of atoms and electrons can be taken from plasma compositions computed without consideration of the N ion

such as those given in Table I. The N\_ number densities given in Table I were determined in this manner. Using these number densities with  $Z^2\bar{g}=1.0$ ,  $Q_{1D}=1.69\times 10^{16}$  (Ref. 10) and  $Q_a=10^{140}$  (Ref. 12) the temperature dependence of the continuum shown in Fig. 6 was computed according to Eq. (9). In the case of air the 0\_ number densities were taken from Ref. 8 and the equivalent absorption crosssection  $Q_{1D}=6.96\times 10^{18}$  was taken from Ref. 10. Because of the exponential dependence of the continuum emission coefficient on temperature below 5000°K, errors in temperature determinations resulting from the assumption of approximately constant cross-sections should be negligible.

#### E. INVERSION METHODS

All experimentally measured spectral intensities were numerically inverted to emission coefficients by means of the Nestor-Olsen 13 method for optically thin plasmas. In the case of the atomic spectral line of nitrogen measured in the high temperature range the inversion was made with absorption corrections using the iterative method recently developed for the Air Force and preliminarily reported in Ref. 14.

#### IV. EXPERIMENTAL PROCEDURE AND RESULTS

The general experimental procedure consisted of three phases which are described below in order of their execution. In the first phase the several forms of discrete radiation were calibrated for use in the following two phases for temperature measurement and ultimately for calibration of the continuous radiation emitted from pure nitrogen and nitrogen—oxygen plasmas respectively. Operating conditions for the two arc jet configurations are given in Table V for all reported results which are generally presented in the graphical form of radial profiles of either emission coefficients or temperature. All measured radiation intensities have been converted to emission coefficients by means of the inversion processes mentioned above. Only the inverted data are reported. Since many profiles are presented to represent original data, sometimes without specific descriptions or discussion in the text, an identifying number is placed on each illustration to correspond with the data description in Table V.

#### A. CALIBRATION OF DISCRETE EMISSION COEFFICIENTS

The emission coefficient for any species of radiation designated by the subscript i may be expressed in the general form

$$\epsilon_i = K_i \epsilon_i^* (N_i, U_i, T)$$

where  $K_i$  is the transition probability for the atomic spectral line or the  $R_e^2$  q factor for the band systems. The function  $\epsilon_i^*$  ( $N_i$ ,  $U_i$ , T) is the normalized emission coefficient described in detail in Section III for all species of discrete radiation considered. As was shown, this function passes through a unique maximum at the "normal" temperature so that the constant  $K_i$  can be determined from the ratio of the measured off-axis peak or "normal" value of the radial profile of the emission coefficient to the computed "normal" value for an LTE plasma. In the case of the electron continuum, where  $\epsilon_i$  has a much more complex form which changes with temperature, this same approach

to the calibration could not be taken. The continuum calibration will be discussed separately below.

Radial profiles of the four different component groupings of the photographed spectrum of Fig. 2 are shown in Fig. 7 as measured in the high temperature nitrogen arc jet where the normal temperature was reached. In the case of the  $R_{16}$  and  $R_{22}$  components, whose normal temperatures exceed 9000°K, the on-axis values were used since there was an observed tendency for flattening of the profile with no further increase in magnitude of the axis values with increased power input or reduced gas flow rate indicating that the normal temperature was just reached on the plasma axis. For each integrated intensity measured on the large spectrograph (LS) a reference measurement was made, simultaneously, on the small spectrograph (SS) using the 3.9 Å increment at the head of the 3914 band ( $\epsilon_{\rm BH}\Delta_1$ ). Corresponding pairs of curves were also obtained with the  $\lambda$ 7468 NI line as reference.

The calibration constants given in the table below were obtained from the ratio of the measured to the computed "normal" values for each of the five species of radiation. Absolute calibration curves can be obtained from the data of Tables I, II and III by direct multiplication with these calibration constants.

Species (i)	λ <sub>o</sub> ** (Å)	Normal Temp.	€; cm <sup>6</sup> -sr <sup>1</sup> -sec <sup>1</sup>	K <sub>i</sub> watt-sec-cm <sup>3</sup>
BH 1-3.9 Å	3912.4	8800	4.23x10 <sup>33</sup>	1.19x10 <sup>36</sup>
BH 2-28 Å	3900.3	9000	7.16x10 <sup>34</sup>	3.0x10 <sup>37</sup>
R <sub>6</sub> Quartet	3905.8	9000	3.13x10 <sup>33</sup>	2.56x10
R <sub>16</sub> Quartet	3894.7	9160	3.80x10 <sup>33</sup>	7.45x10 <sup>37</sup>
R <sub>22</sub> Quartet	3885.8	9240	3.97×10 <sup>33</sup>	1.82x10 <sup>37</sup>
R <sub>38</sub> Sextet	3322.9	8300	9.09x10 <sup>32</sup>	1.63x10 <sup>37</sup>
			watt-cm <sup>-3</sup> -sr <sup>-1</sup> -sec	sec 1
Atomic Line	7468.3	15000	1.86x10 <sup>7</sup>	1.72x10 <sup>7</sup>

<sup>\*\*</sup> Center wavelength

Because of the predominant increase in interfering band and line radiation which accompanies an increase in width of the wavelength increment of the band at high temperatures (see Fig. 2), determination of the  $R_2^2$  q factor for the 28 Å (BH $\Delta_2$ ) increment could not be accomplished at the normal temperature by comparing measured and computed off-axis peaks of the emission coefficient as in the case of the 3.9 A increment. It was found more practical to use the previously calibrated 3.9 A increment to calibrate the 28 A increment at lower temperatures. The dual recording system was used for simultaneous recording of intensities of the two band increments in a common volume of the plasma. Using a common pair of measured radial distributions the calibrated emission coefficient of the 3.9 A increment was used to determine the temperature of the common volume element and the absolute value of the corresponding 28 Å increment emission coefficient was then compared with its normalized value to yield the best average R q factor given in the table above. The experimental data used in this calibration are from runs 49 through 59 of Table V.

In order to obtain an independent calibration for the  $\lambda$  7468 NI line the free-burning nitrogen arc was used since its axis temperature exceeds the normal temperature for the line. Radial profiles of the emission coefficient measured in the mid-plane with electrodes separated 0.3 inch are shown in Fig. 8 for both the absorption corrected and uncorrected case. The absorption inversion computer program described in Ref. 14 was used for the correction. The transition probabilities (calibration factor) obtained with and without absorption correction are 1.72 x  $10^7$  sec<sup>-1</sup> and 1.39 x  $10^7$  sec<sup>-1</sup> respectively which are to be compared with 1.61 x  $10^7$  sec<sup>-1</sup> published by the NBS.

#### B. NITROGEN PLASMA JET TEMPERATURES

The photographed spectra of Fig. 2 show that, of all of the resolved quartet groups, the R<sub>22</sub> component is the best choice for temperature measurements since it is free from interference at all temperatures. The same is true for the 3.9 Å band head increment which also has the advantage of a good clear portion of the continuum background (not observable in Fig. 2) immediately adjacent to it. The close spacing of the

components in the region of  $R_{\mbox{\scriptsize f}}$  and the interfering spectral line near R<sub>16</sub> make it difficult to obtain accurate intensity measurements of these two components with proper background corrections. The observed higher value of K; for the R16 component given in the table above clearly shows the effect of this line interference. Typical experimental results for all species under differing operating conditions are given in Figs. 9 through 13. The results of such measurements for all of the species mentioned above are shown in Figs. 14 and 15. These results show very good agreement for the  $\lambda$ 3914 R<sub>6</sub> component, BH $\Delta$ <sub>1</sub>,  $\lambda$ 3371 R<sub>38</sub> component, and the  $\lambda 7468$  atomic line. The consistently lower temperatures obtained from the R<sub>16</sub> component result from the interference as is also the case for the  $R_{\mathbf{3}\mathbf{8}}$  component at high temperatures. The erroneously high temperatures obtained from the continuum result from the application of the Kramers-Unsöld theory for ion-electron interaction only with  $Z^2 \bar{g} = 1$  which has been found to give theoretical values for the emission coefficient which are considerably lower than measured values; the difference increases sharply with temperature reduction.

These experimental results show that the  $\lambda$  3914 BH $\triangle$ <sub>1</sub> and  $\lambda$ 7468 atomic line constitute the best detectors for high temperature plasmas. To further demonstrate the consistency of this spectroscopic method for temperature measurements the  $R_{22}$  component of the  $\lambda$  3914 band and the  $R_{38}$  component of the  $\lambda_{3371}$  band have been measured in combination with the (BH $\Delta_1$ ). Figures 16 and 17 show radial temperatures down to  $4800\,\mathrm{^oK}$ . Similar data for the  $\mathrm{R}_{38}$  component are given in Fig. 18. The level of temperature was changed by down stream gas dilution. Note that as the enthalpy is reduced by the dilution it is essentially the center temperature which is reduced. The dilution needed to drop the temperature level corresponding with the lower limit of the radiation detector is less for the weaker R38 component of the neutral band system than for the Roo component of the ion band system. The excellent agreement of the temperatures obtained from data of the two systems when compared with the common ion band head increment is strong evidence for local thermal equilibrium in nitrogen plasmas down to temperatures as low as 4800 °K.

The measurement of temperatures has also been extended to lower levels while using the  $\lambda$ 7468 atom line. Comparisons of the results with those obtained from the  $\lambda$ 3914 BH $\Delta_1$  increment (3.9 Å) are given in Fig. 19. The fact that the atomic line consistently gives higher temperatures is an indication that either or both species were not properly calibrated. It was for this reason that the transition probability for the atomic line was checked with the free-burning arc as discussed above. The observed agreement of the measured transition probability with published values would tend to indicate that the  $R_e^2$  q factor for the band system may still be in question. Since the measurement of temperatures using the band head increment at lower levels is not very sensitive to the adjustment of the  $R_e^2$  q factor required to bring these results into agreement and, in addition, the  $\lambda$ 7468 line is a very poor diagnostic probe for temperatures below 6000°K, improvements in this absolute calibration were not pursued further.

Increasing the band head increment to 28 Å (BH $\Delta_2$ ) gave a higher signal-to-noise-ratio and thus smoother intensity traces at lower levels of temperature. Because of the discriminatory increase in background continuum with the wider slit, the lower temperature limit of applicability was not adjusted downward appreciably in comparison with that obtained with the 3.9 Å (BH $\Delta_1$ ) increment. Application of the broad increment was further limited by the fact that when attempting to apply it to a portion of the  $\lambda$ 3371 band system it was not possible to find an adjacent region of the continuum that is free from interference from other discrete radiations over a sufficiently large interval to permit proper correction for the background.

The optical system used to this point in the investigation was designed to give spatial resolution in the source by using a narrow entrance slit  $(50\,\mu)$  and a magnifying optical system (5X). With this system some trade-off between resolution and signal to noise ratio was provided by a choice of entrance slit lengths ranging from 0.02 in. to 0.16 in.; high resolution was obtained at the expense of radiation sensitivity. Extension of measurements to lower temperatures and,

consequently, lower intensities required this trade-off between spatial resolution and light-gathering power of the total spectral detection system.

The optical system, external to the spectrograph, was modified by moving the focusing lens to its conjugate point thus producing a 4 to 1 reduced image of the source of the entrance slit. The two optical systems are identified in Table V by either a +5 or -4 magnification. The best results were obtained with a compromise solution which sacrificed resolution equally in two dimensions by using an entrance slit with identical length and width dimensions of 0.02 in. in combination with the reduced image of the source. The results of temperature measurements using this modified optical system and the 3.9 A (BH $\Delta_1$ ) increment of the ion molecular band are shown for Run #81 in Fig. 22a where the lower limit for temperature measurement has been extended to 3700°K. The PSL instrumentation previously used at AEDC consisting of a small  $\frac{1}{4}$  meter spectrograph in combination with an attached lens mounted on a transport table to constitute a spectral probe, was used in the same manner as the modified optical system to determine the lower temperature limitation for such a probing system. The results given in Fig. 22b show a lower temperature limit of 3825°K for this system.

The sacrifice of spatial resolution discussed above is not as serious as it might first appear. It should be noted that the plasmas investigated at PSL have diameters ranging from 0.25 in. to 0.50 in. whereas practical testing devices used by the Air Force are in the range of 1 to 2 in. dia and have considerably longer flames. The sacrifice of spatial resolution for increased sensitivity does not, therefore, appear to lead to serious limitations of these diagnostic methods in practical applications.

As has been previously reported<sup>1,3</sup> the intensity level of the continuum is considerably higher than that computed on the basis of the Kramers-Unsöld theory for ions and electrons alone. While investigating nitrogen plasmas at successively lower temperatures it was found that the corresponding emission coefficients dropped much faster

for the 3.9 Å (BH $\triangle_1$ ) increment of the  $\lambda$ 3914 band than for the background continuum. Even though attempts could be made to develop more sensitive detectors for this species of radiation, a lower limit would ultimately be reached where the desired signal would blend in with the background continuum. Beyond this level no further improvement in the detector sensitivity would be useful. Such a limit has been experimentally determined by observing the point at which the band 3.9 Å (BH $\triangle_1$ ) increment of the  $\lambda$ 3914 band merges into the background radiation. This occurs at 3700°K for the one atmosphere nitrogen plasma.

#### C. EXPERIMENTAL CALIBRATION OF NITROGEN CONTINUUM

At the lower levels of temperature of a one atmosphere pure nitrogen plasma, where no discrete radiation can be detected for the band systems, there remains a very measureable continuous radiation. The earlier choice of discrete radiation for temperature measurements was made because experimental results could be compared directly with theory for calibration. This is not the case for the continuum. At best, as discussed in Section III, the theory can only be used as a guide for extrapolation, to lower temperatures, of the experimentally measured emission coefficients plotted against the temperature determined from the band head increment at higher temperatures where the two species of radiation can be simultaneously measured.

To obtain a calibrated spectral probe which can cover a wide range of temperature it was necessary to look not only at plasmas of various average temperatures but to look also at different positions in the plasmas. Average gas temperatures were determined from heat balances at the exit of the flame. Table V gives the pertinent data on the various plasmas investigated where Z represents the distance from the exit of the jet. The experimental data points of Figs. 23 and 24 were obtained with the same entrance slit width (0.02 in.) but with different slit lengths and different exit slit widths. Both figures include data obtained at two wavelengths, i.e.,  $\lambda$ 5600 and  $\lambda$ 3920 Å. The observed wide spread is due mainly to the recognized fact that at longer wavelengths the continuum has a higher emission coefficient yet no

attempt has been made to compensate for this fact in these composite plots. Also a clear indication of impurity radiation in the  $\lambda$  5600 Å region was observed for the jet and might account for some of the spread of data. Temperatures were determined from emission coefficients of  $\text{BH}\Delta_1$  or  $\text{BH}\Delta_2$  measured simultaneously with the large spectrograph. The temperature profile of Fig. 22C was obtained from the emission coefficient of the 28 Å increment of the  $\lambda$ 3920 continuum by comparison with the extrapolated (solid) curve of Fig. 23. The source of this curve is discussed in detail in Section V.

## D. EXPERIMENTAL CALIBRATION OF NITROGEN-OXYGEN CONTINUUM

This laboratory is equipped to experiment with air plasmas only in the form of nitrogen-oxygen mixtures because the arc jet in operation employs a thoriated tungsten cathode which must be protected from any oxidizing atmosphere. The oxygen was introduced downstream of the cathode region of the nitrogen plasma yet upstream of the point of arc attachment to the anode. Air plasma simulation was obtained by selecting a mixture of 20.9% oxygen by volume indicated on flowmeters at room temperature.

Table V summarizes the experimental conditions in the series of tests involved in this investigation where arc jet III was used mainly. The mixture flow rates were limited to two levels, i.e. 111 scfh and 141 scfh. The selection of different temperature profiles was achieved by probing at different distances from the jet exit (Z). The entrance slit used was 0.02 in. x 0.02 in. with either spectrograph. The exit slits were selected to adapt to the species of radiation considered. The  $R_{38}$  component of the neutral band system ( $\lambda$ 3371), 3.9 Å (BH $\Delta_1$ ) and 28 Å (BH $\Delta_2$ ) increments of the ionized band system ( $\lambda$ 3914), and the  $\lambda$ 7468 atomic nitrogen line were the three species used.

Profiles of the emission coefficient for the plasma flame at different distances from the jet axis for two different flow rates are shown in Figs. 25 and 26. Temperatures determined from the latter

set are shown in Fig. 27. The corresponding  $\lambda 3914$  band increment or atomic line has been used to determine the temperature profile of the jet in the range where these species emit and just above the level where the radiation disappears into the background continuum. For the band head this occurs at  $4500\,^{\circ}$ K and for the atomic line at  $5000\,^{\circ}$ K. These temperature profiles obtained with the  $R_{38}$  component of the neutral band and the 3.9 Å (BH $\Delta_1$ ) increment of the molecular ion band measured at the same position in the simulated air plasma are shown in Fig. 29. It is to be noted that all of the species investigated give the same temperature profile in the temperature range covered.

In a manner similar to that described above for pure nitrogen plasmas, both the 3.9 Å (BH  $\Delta_1$ ) and 28 Å (BH  $\Delta_2$ ) increment of the ion band system have been used to calibrate the continuum which is the only radiation detectable below 4500 K. Calibration curves for the continuum obtained by comparison with the 3.9 Å wavelength increment at  $\lambda$ 3920 Å for 111 scfh and 141 SCFH are shown in Figs. 30 and 31 respectively. Here, as in the case of nitrogen, the temperature was determined from the simultaneously measured  $\lambda$ 3914 BH  $\Delta_1$  emission coefficient using the large spectrograph. The temperature scale of Fig. 30 was established by referring the measured BH  $\Delta_1$  emission coefficient to the temperature profile computed for the equilibrium air plasma. The temperature scale of Fig. 31 was established by reference to the temperature profile of BH  $\Delta_1$  computed for a 79%-21% mixture of equilibrium nitrogen and oxygen plasmas. This is discussed further in Section V.

An rf plasma was used to investigate the air plasma in an effort to observe any possible effects of gas mixing. Stable plasmas were induced in both air and nitrogen at plate power inputs ranging from 50kw to 100 kw and in a 4 in. dia, air cooled, transparent quartz tube with swirl gas flow ranging from 30 to 50 scfh. The optical system reduced the image of the source at the spectrograph slit to one seventh of its actual size. A pre-calibrated tungsten lamp was used as a radiation standard.

Because of strong rf interference with the X-position and intensity signals, graphic recording of radial intensity profiles was

difficult. This interference was minimized by zeroing out the rf background signal. The 3.9 Å (BH $\triangle_1$ ) increment of the  $\lambda$ 3914 band and the  $\lambda$ 7468 atomic line measured on the large spectrograph were both used in conjunction with separate traces of their respective continua in the air and nitrogen rf plasmas. Figure 32 gives the emission coefficient ( $\epsilon$ ) profiles and Fig. 33 the temperature profiles for these experiments. Figure 34 shows the experimental calibration curves for  $\epsilon$  versus T for the corresponding continuum, using for reference the temperatures measured with both the band head increment and the atomic line.

Considering the difficulty encountered with intensity recording in the presence of rf interference these results look satisfactory. The temperature given by the atomic line looks higher because no correction has been made for self-absorption in the large diameter plasma. This effort was not pursued further because it was obvious that the range of temperatures encountered was too high to permit any definite selections of the calibration curves for nitrogen-oxygen mixtures.

## V. DISCUSSION

The forms of empirical curves that have been fit to measured temperature profiles for the electron continuum (see Fig. 23) can best be understood by refering to the type of log-log plot of Fig. 35. On such a plot any simultaneous measurement of the two emission coefficients in a given volume of plasma uniquely defines an experimental point. In this way data from any plasma at the same pressure can be compared. For example the data points indicated by (x) were obtained from the high temperature jet (I) and those by (0) from the low temperature jet (III). The analytical equilibrium characteristic curve, shown in Fig. 35 for comparison, was obtained by plotting the computed emission coefficient of the total continuum of Fig. 6 as ordinate against that of the BH $\Delta_1$  increment of the molecular ion band (taken from Table IV after correction with the experimentally determined calibration constant) as abcissa with temperature as parameter.

The data presentation of Fig. 35 vividly shows the existing discrepancy between theory and experiment for the electron continuum in nitrogen. This discrepancy can be interpreted in terms of either or both of the species of radiation. Since the ion band increment has been shown to give temperatures which are in excellent agreement with those obtained from both the neutral band and the atomic line, it is not conceivable that such a large discrepancy can be interpreted by an error in relating the analytical data to temperature determined from BH $\Delta_1$ . It is, therefore, assumed that the total electron continuum calculated from nitrogen has not been properly related to temperature. As the dashed curve shows, an increase of the neutral molecule absorption cross-section by nearly six orders of magnitude would be needed to bring the data into agreement at 4000°K but would still not yield a slope which fits the experimental points. It has been found, however, that an empirical curve E = kNoN fits very well in the low temperature range and can be used to extrapolate the

experimental calibration curve for the continuum to lower temperature where the discrete radiation is completely masked by the continuum as a background. The horizontal and vertical dashed lines are drawn in Fig. 35 to denote the temperature level of ~ 4000°K below which the continuum becomes equal to or stronger than the band radiation. The solid curves of Figs. 23 and 24 show the low temperature extrapolation of this empirical 1 atm nitrogen curve.

Attempts to fit three different sources of the continuum in an air plasma to the experimental data of Fig. 30 obtained from a nitrogen-oxygen mixture were not successful as in the case of the nitrogen plasma. The observed similarity in shape of the nitrogen empirical curve (shown for comparison in Fig. 30) with the data for a nitrogen-oxygen mixture leads one to suspect that the relatively slow

$$N0 \Rightarrow N0^+ + e$$

reaction which accounts for the considerably higher electron density and consequently a strong 0\_ continuum is not complete in the mixed plasma jet because of insufficient residence time or incomplete mixing of the added oxygen. The absence of NO was practically observed by the conspicuous lack of the characteristic odor during extended periods of operation of the nitrogen-oxygen jet without the quench chamber. Since the absence of this reaction in the nitrogen-oxygen mixture would cause the number densities of electrons and neutral molecules to be lower and the number density of ionized molecules to be higher than in an equilibrium air plasma, the experimental data points of Fig. 30 would tend to be shifted to lower temperatures and the empirical curve € = 2.2 x 10 48 N2Ne shifted to lower intensities.

To test the hypothesis that the NO reaction has not been completed in the nitrogen-oxygen plasmas investigated, the temperature dependence of the emission coefficients  $\mathbf{E} = k N_2 N_e$  and BH $\Delta_1$  have been computed from number densities taken as 79% of those for an equilibrium nitrogen plasma and 21% of those for an equilibrium oxygen plasma. The particles in a given volume element resulting from the two independent plasmas are

then assumed to be thoroughly mixed. The experimental data points of Fig. 31 have been plotted against temperatures obtained from the BH  $\triangle_1$  increment for this hypothetical mixture. The solid curve has also been computed for the hypothetical mixture assuming the same proportionality constant as determined for the nitrogen plasma. The observed agreement seems almost fortuitous; more experimental and theoretical work is needed to confirm this hypothesis than was possible within the scope of this investigation.

In the same manner as was done for the nitrogen plasma, the original data from which the plot of Fig. 31 was made have been compared in Fig. 36 with the equilibrium characteristic curve for air at 1 atm. These results are rather startling and, in fact, somewhat disturbing when compared with the similar comparison (Fig. 35) for nitrogen. One's first interpretation is that the contribution to the air continuum by recombination to form the 0 ion accounts for raising the computed continuum into much better agreement with experimental results; this is in direct contradiction with the observations made above. Alternatively, it might be argued that the enhancement of the experimental continuum for the nitrogen plasma results from an impurity of oxygen. This has, however, been completely ruled out by the observed fact that the same experimental results have been obtained from the nitrogen plasma exhausting directly into room air or into a nitrogen filled quench chamber. Furthermore, the agreement of the shape of the experimental curve of Fig. 31 with the empirical curve for the hypothetical plasma and the significant disagreement with the equilibrium air curve lends strong support to the hypothesis of the mixed nitrogen and oxygen plasmas.

In order to resolve the problems raised by this investigation on "air" plasmas it would be necessary to operate on "pure" air plasmas such as are in operation in the Air Force Research and Development Laboratories. It should be noted that, despite the extensive use of air plasmas for material testing the only quantitative work on the emitted continuum has been carried out on rf plasmas or shock tubes \$15,16\$ at temperature above 6500°K where agreement with the theory is relatively good. Infrared measurements made by Taylor on shocks in

nitrogen and air at wavelengths greater than  $^2\mu$  are found to be of the same order of magnitude as the results of this work in the UV. From the computed wavelength dependence of the Bremsstrahlung for both nitrogen and air this should be expected. In the case of nitrogen the experimental results reported here are in agreement with Morris, et al. at the 9000 k point. Lower temperatures were not reported in the reference because of claimed deviations from equilibrium. Hammerling, Tear and Kivel have shown that in shock tubes the  $N_2^+$  radiation overshoots its equilibrium value during relaxation due to coupled vibration dissociation. This effect can be neglected here since the relaxation time is of the order of  $^1\mu$  sec and, more significantly, the effect would be to shift the calibration curves for the continuum in the opposite direction of that observed here.

## VI. CONCLUSIONS AND RECOMMENDATIONS

It can be concluded from the results of this investigation that, at least in the case of nitrogen, the measured continuum below 5000°K at atmospheric pressure is proportional to the product of the number densities of neutral molecules and electrons yet considerably greater than that given by the theory for the electron continuum emitted by an equilibrium plasma. The extrapolated calibration curve given in Fig. 37 shows that for a detection limit of  $10^{23}$  watt-cm<sup>3</sup>-sr<sup>1</sup>-sec, which is estimated for the existing diagnostic facilities, the lower limit for temperature measurements in a 1 atm nitrogen plasma is 2900°K. At higher pressures, for example 50 atm, the lower temperature limit is reduced to 2400°K assuming the same calibration constant. Furthermore, changes in pressure from 10 to 50 atm at 3000°K results in only a 250°K change in temperature for a given emission coefficient as shown in Fig. 37.

Initial attempts to develop a similar calibration curve for the 1 atm air plasma by applying the same analytical and experimental methods to a mixed nitrogen-oxygen plasma jet have led to the conclusion that the jet really behaves as a 79%-21% mixture of equilibrium nitrogen and oxygen plasmas. Contrary to observations with the nitrogen plasma the continuum measured in the mixed plasma agrees relatively well with the analytical data computed for an equilibrium air plasma. The curves of Fig. 37 show that for a given measured emission coefficient the temperatures determined by the two calibration curves would differ by only 400°K at 3000°K. Assuming that the same relationship holds at elevated pressures, the same temperature limits can be hypothesized.

It is recommended that the diagnostic methods and apparatus developed under this contract be used to establish the lowest level

of temperatures encountered in a practical Air Force testing facility. A more extensive follow-on research and development program should then be undertaken to investigate the air plasma with the same thoroughness as reported here for the nitrogen plasma. With a proper calibration of the low temperature air continuum a rapidly scanning diagnostic system can be designed for the monitor and control of practical material testing facilities.

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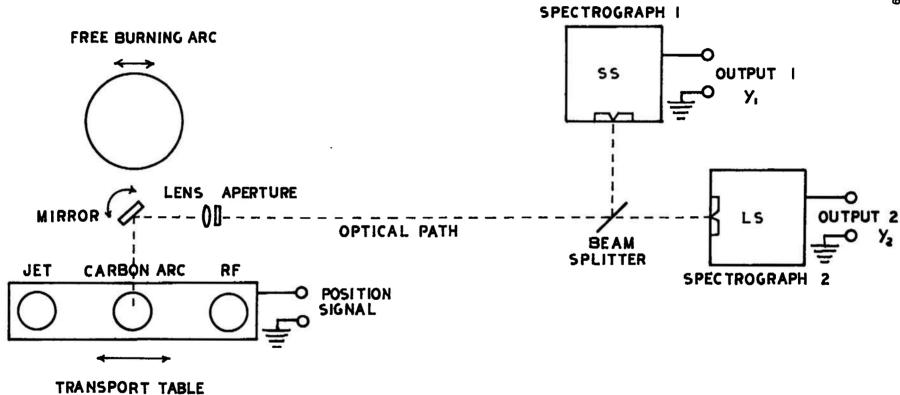


Fig. 1. Schematic diagram of experimental apparatus.

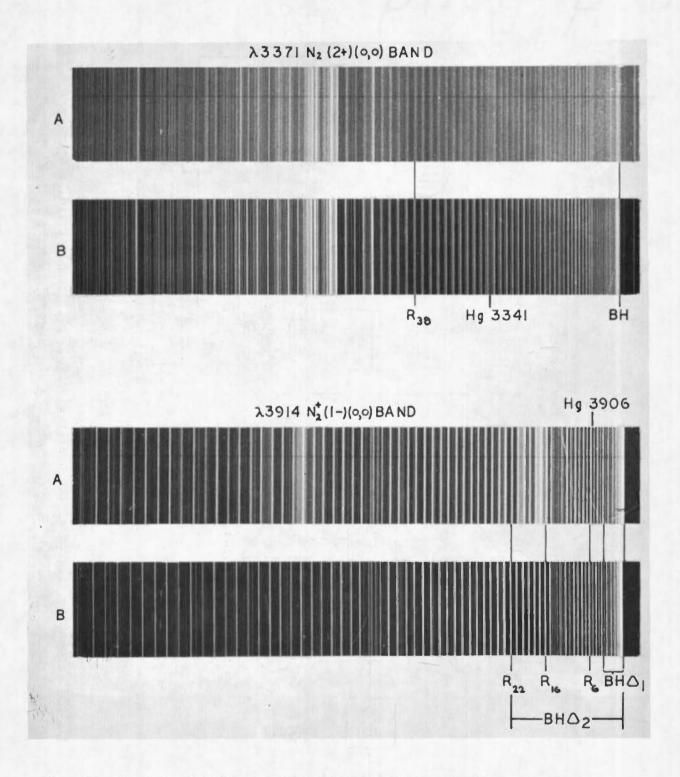


Fig. 2. Spectra of neutral and ionized nitrogen molecules emitted by 1 atm nitrogen plasmas in high (A) and low (B) temperature ranges.

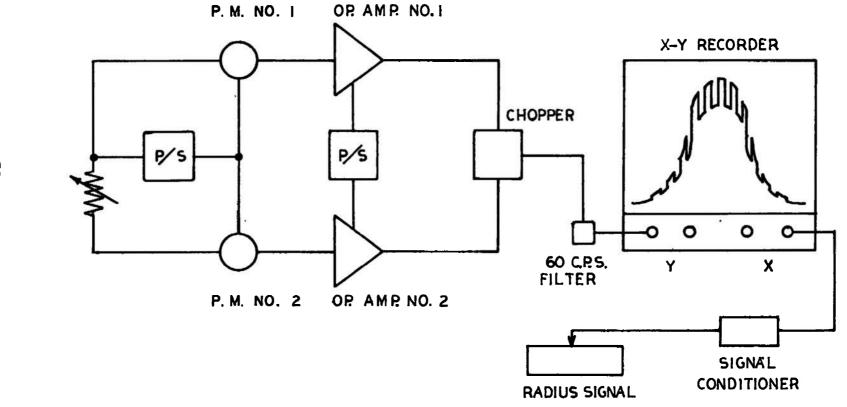


Fig. 3. Schematic diagram of the dual recording, split beam, optical system.

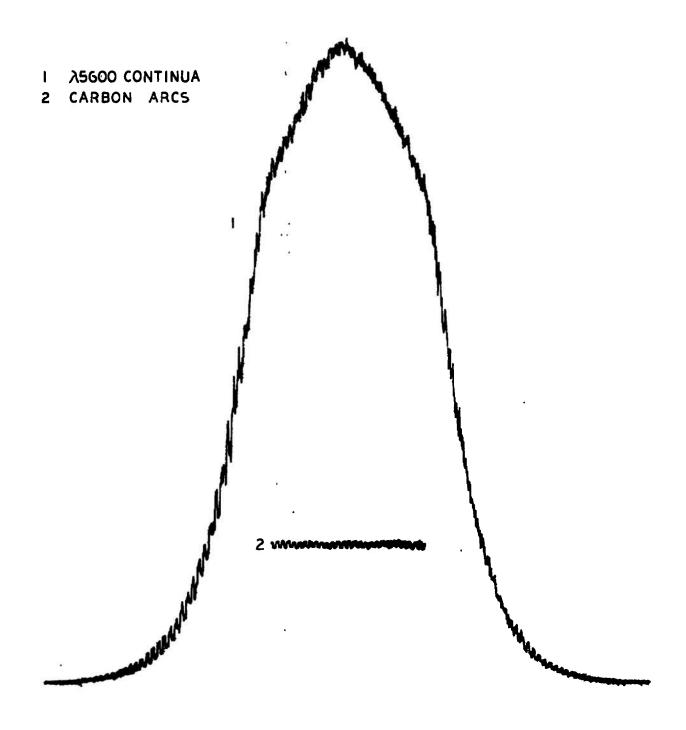


Fig. 4. Simultaneous recording of the  $\lambda$  5600 continuum (on both spectrographs) using the chopped x-y recording system.

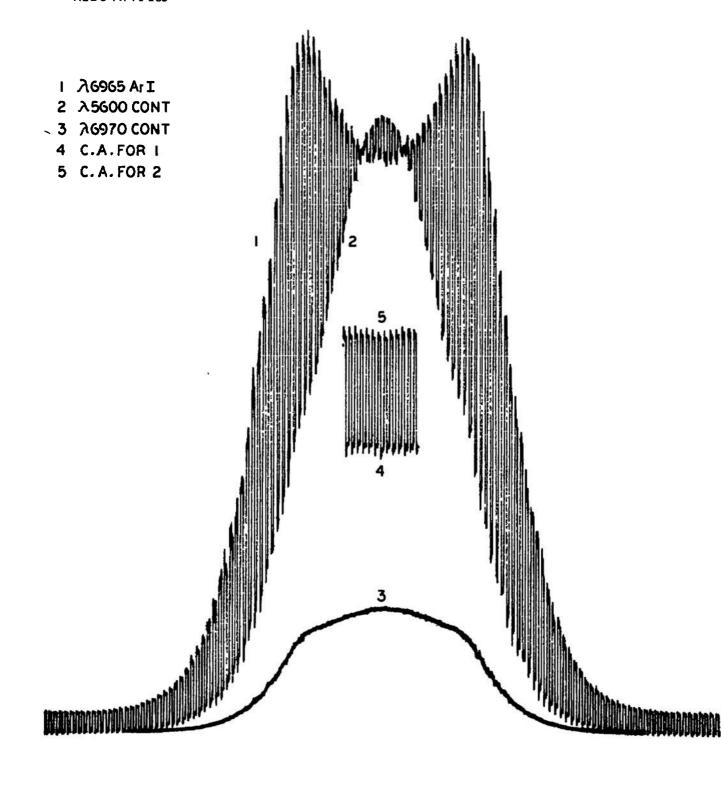


Fig. 5. Simultaneous recording of the  $\lambda$ 6965 Ar I atomic line and the  $\lambda$ 5600 continuum using the chopped x-y recording system.

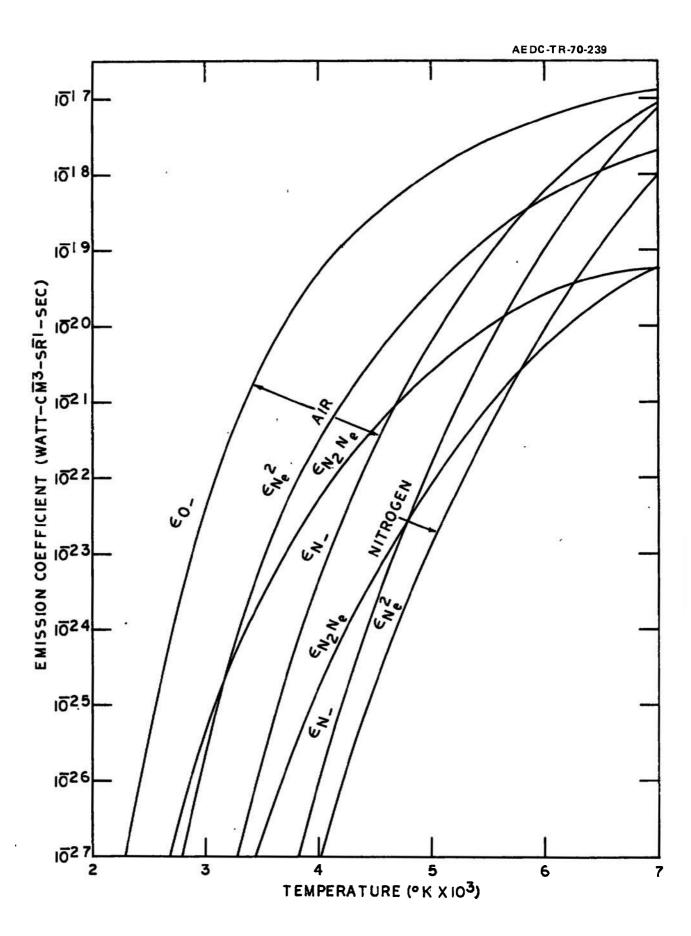


Fig. 6. Computed absolute emission coefficients of the several sources of continuum emitted by 1 atm nitrogen and air plasmas.

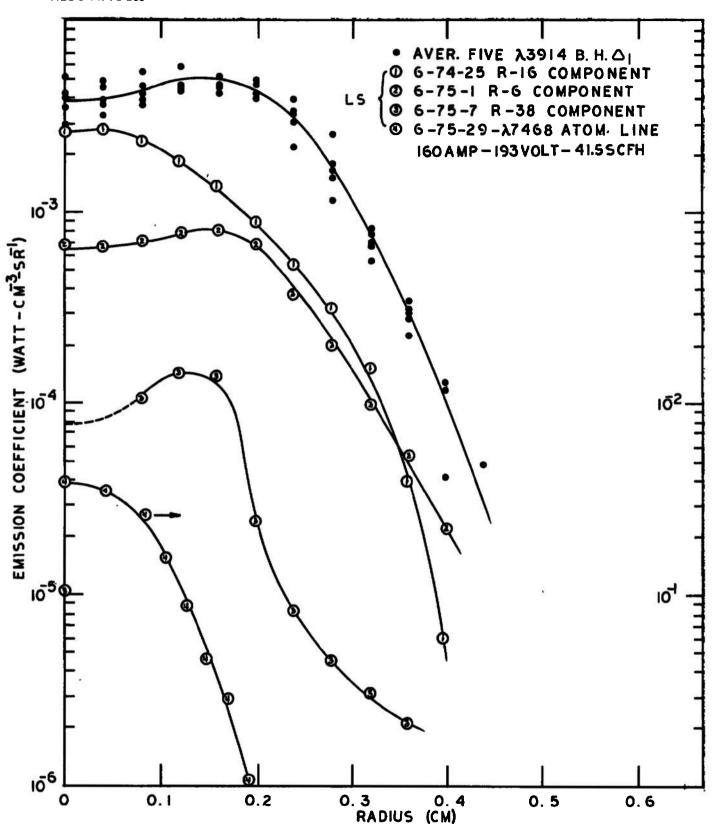


Fig. 7. Measured radial profiles of the emission coefficient for several species of radiation emitted by the nitrogen plasma at 1 atm.

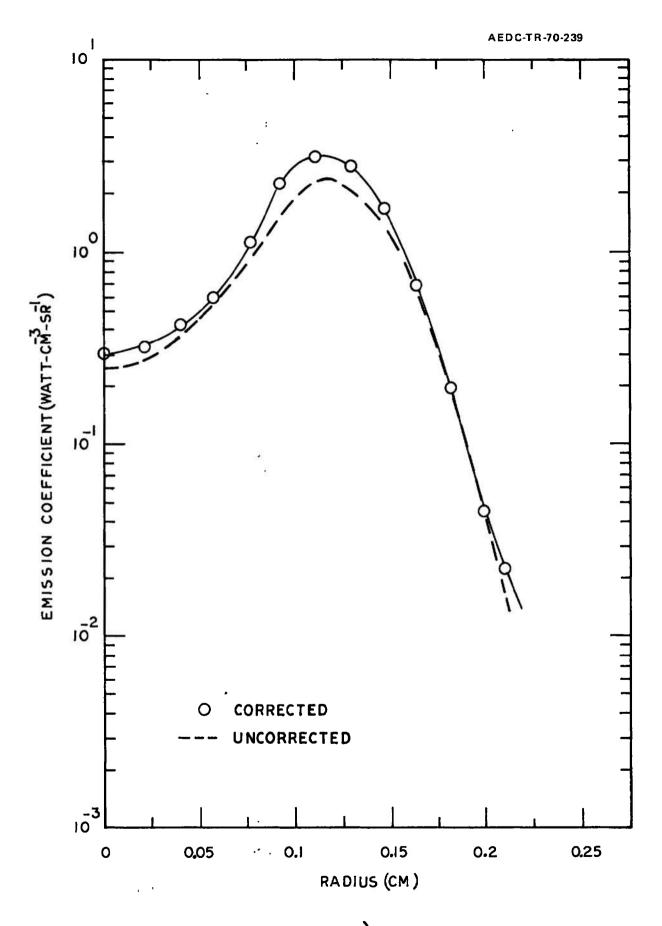


Fig. 8. Measured radial profile of the \$\lambda 7468 NI line emission coefficient emitted by a 1 atm free-burning nitrogen arc with and without absorption correction.

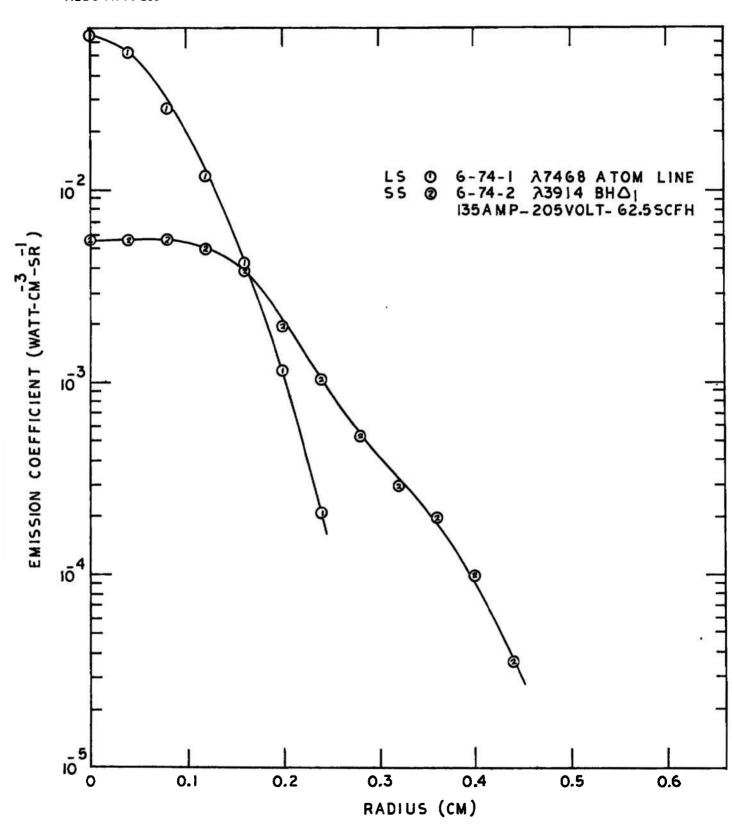


Fig. 9. Emission coefficient vs radius for the  $\lambda 3914$  BH  $\Delta_1$  increment and the  $\lambda 7468$  atomic line in a 1 atm nitrogen plasma jet at 62.5 scfh gas flow.

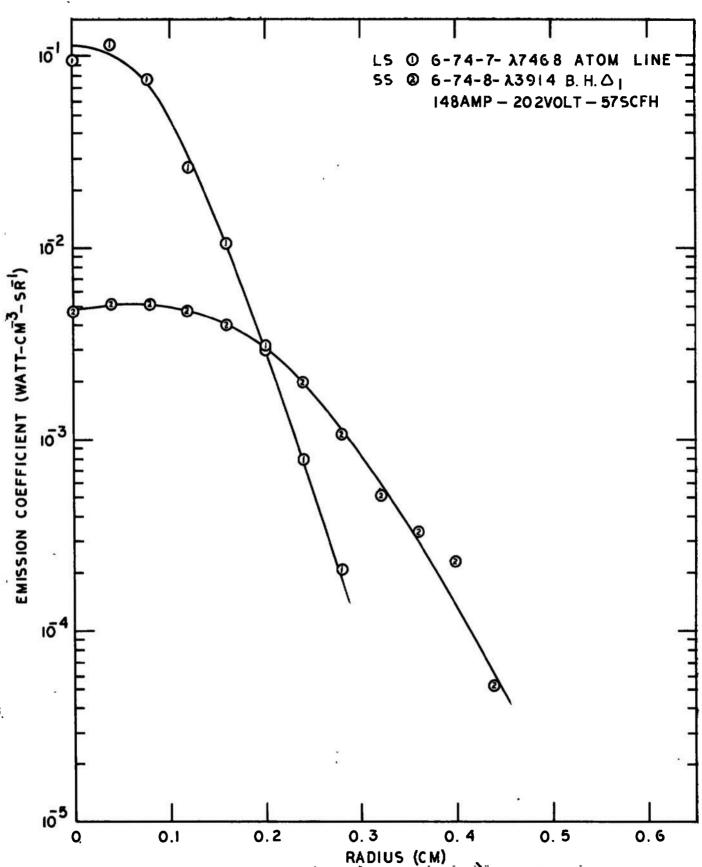


Fig. 10. Emission coefficient vs radius for the \$\lambda 3914 BH \$\Delta\_1\$ increment and the \$\lambda 7468 atomic line in a 1 atm nitrogen plasma jet at 57 scfh gas flow.

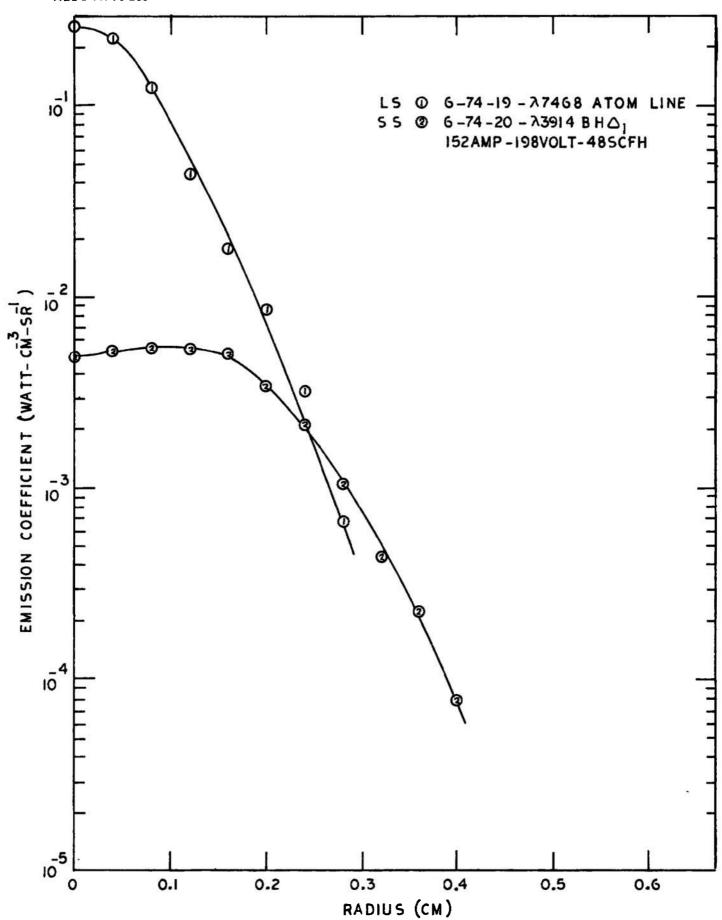


Fig. 11. Emission coefficient vs radius for the  $\lambda 3914$  BH  $\Delta_1$  increment and the  $\lambda 7468$  atomic line in a 1 atm nitrogen plasma jet at 48 scfh gas flow.

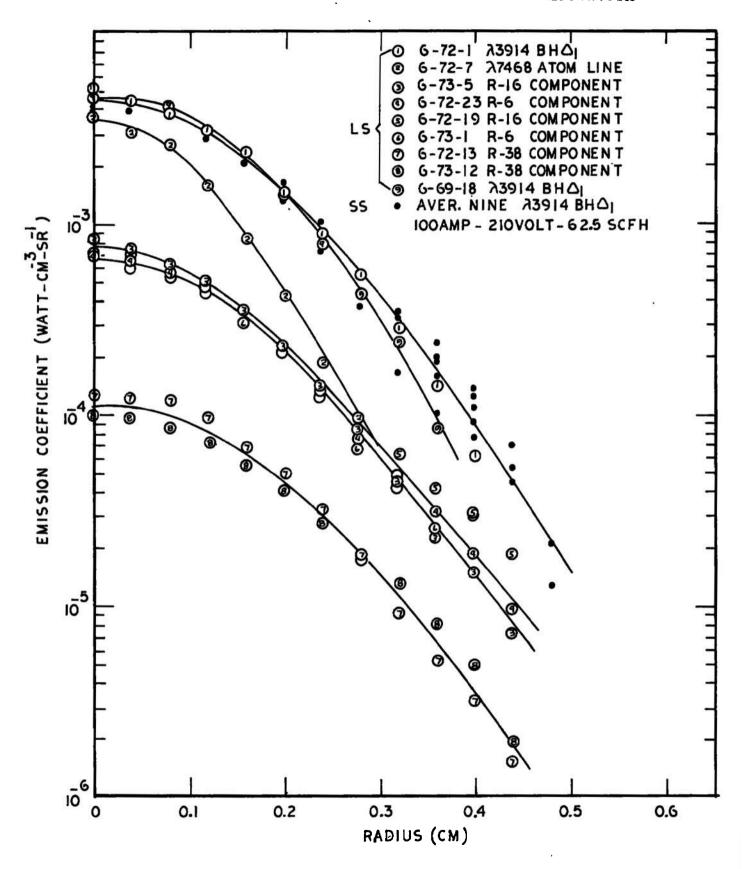


Fig. 12. Composite radial plots of emission coefficients for several species of radiation for a 1 atm nitrogen plasma jet at 62.5 scfh gas flow.

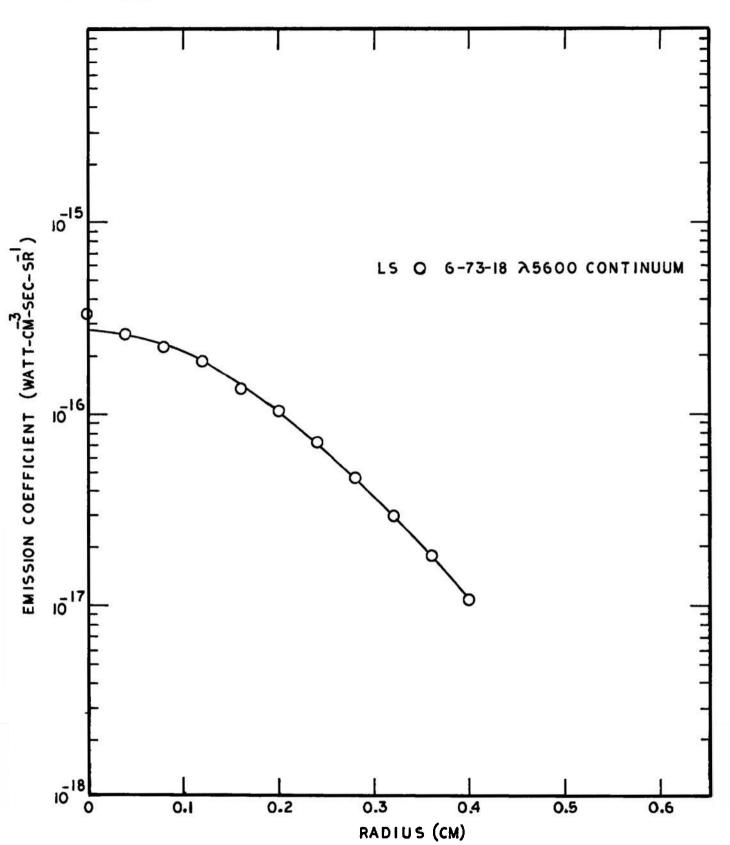


Fig. 13. Emission coefficient vs radius for the  $\lambda$ 5600 continuum in a 1 atm nitrogen plasma jet at 62.5 scfh gas flow.

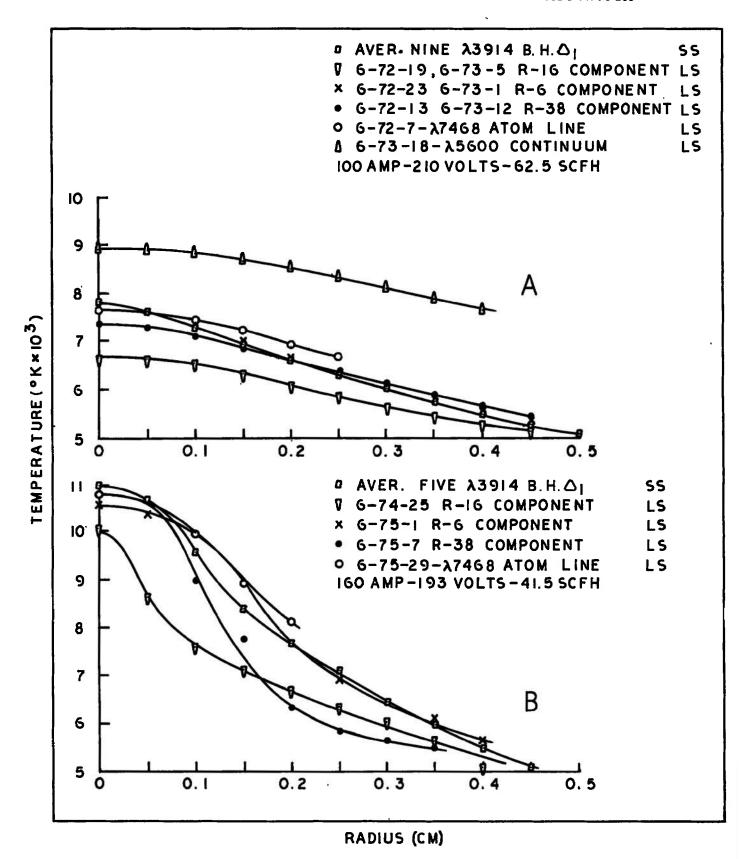


Fig. 14. Radial temperature profiles determined from data of Figs 7, 12 and 13 using calibrated emission coefficients.

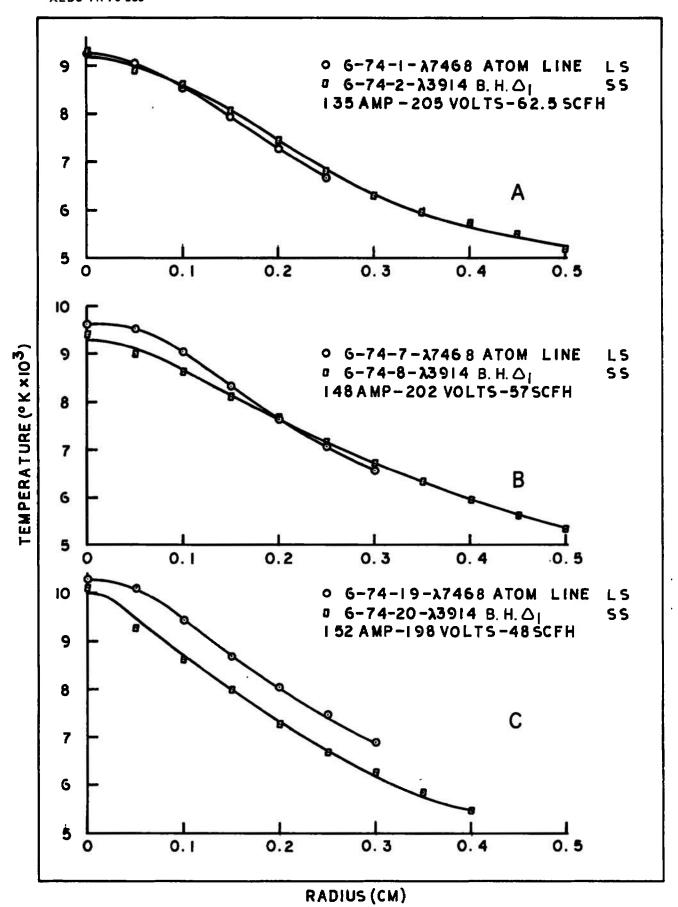


Fig. 15. Radial temperature profiles determined from data of Figs. 9, 10 and 11 using calibrated emission coefficients.

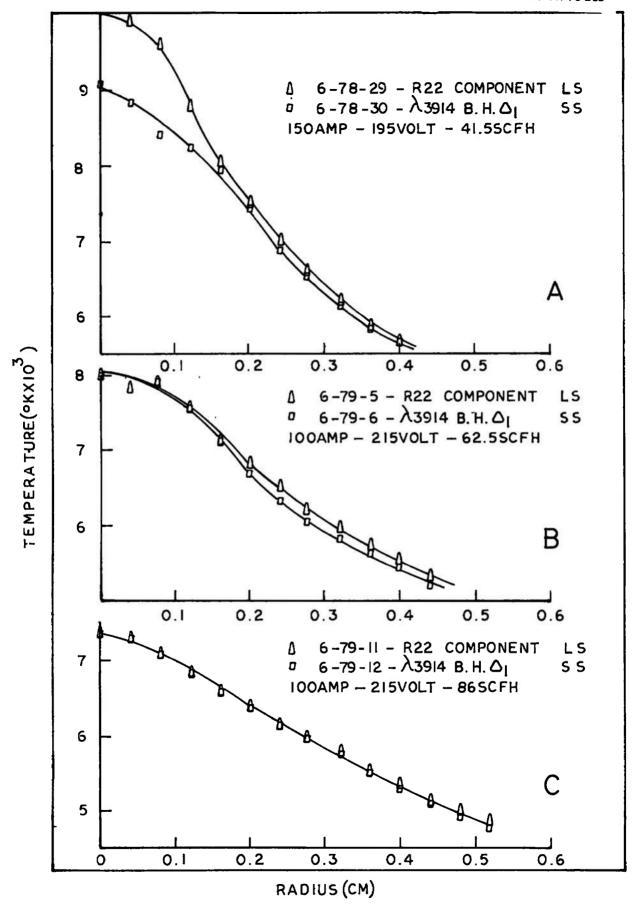


Fig. 16. Comparison of radial temperature profiles determined from the  $\lambda$ 3914 BH $\Delta_1$  increment and the R<sub>22</sub> component for several gas dilutions at low flow rates.

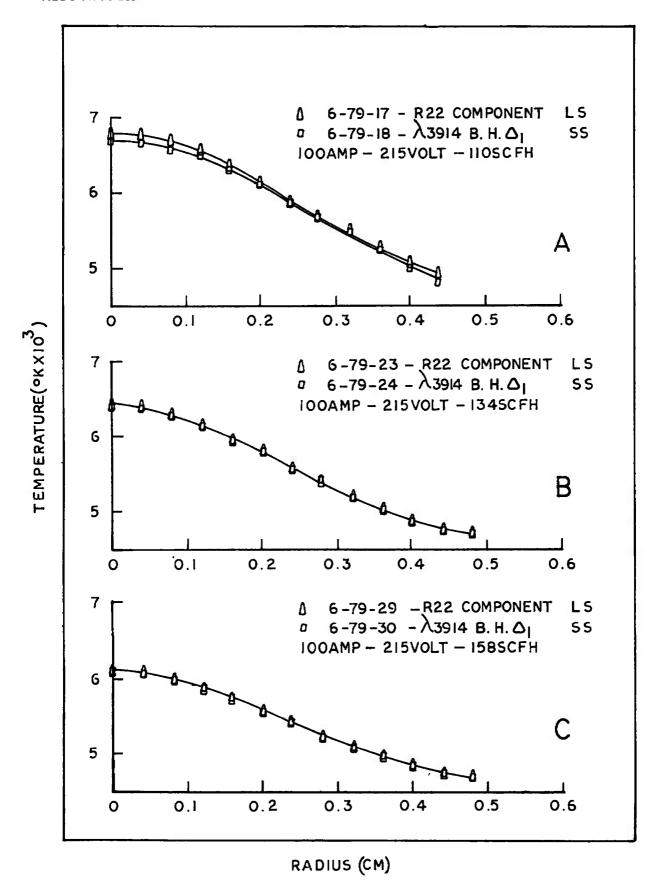


Fig. 17. Comparison of radial temperature profiles determined from the  $\lambda$  3914 BH $\Delta_1$  increment and the R $_{22}$  component for several gas dilutions at high flow rates.

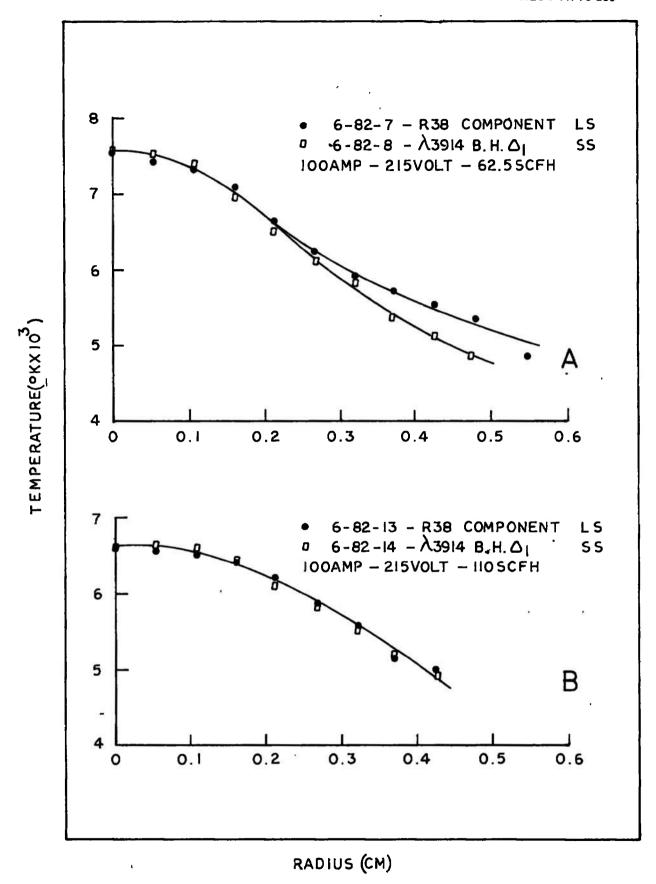


Fig. 18. Comparison of radial temperature profiles determined from the λ 3371 R<sub>38</sub> component and the λ 3914 BHΔ<sub>1</sub> increment for two gas dilutions.

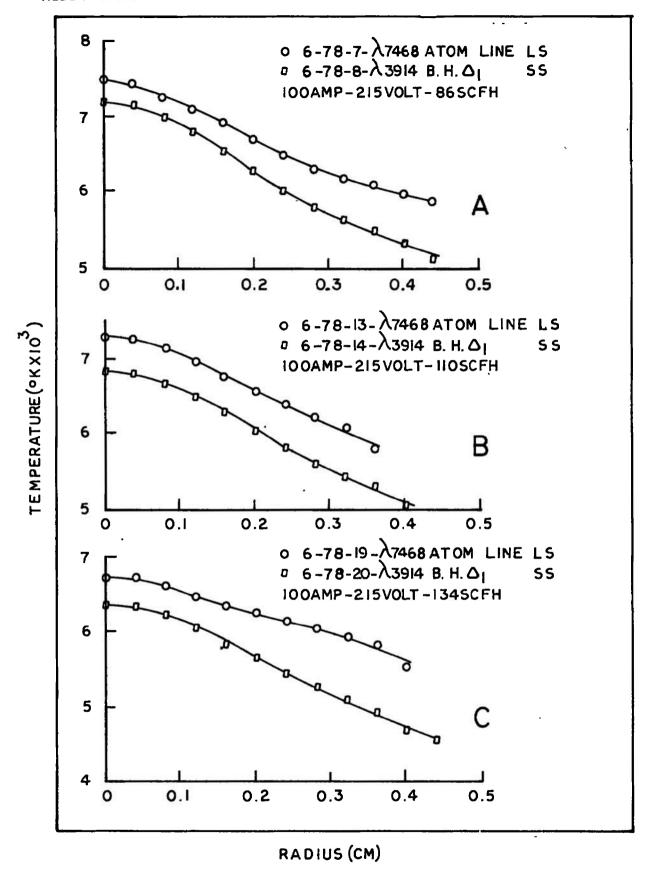


Fig. 19. Comparison of radial temperature profiles determined from  $\lambda$  7468 atomic line and the  $\lambda$ 3914 BH $\Delta_1$  increment for several gas dilutions.

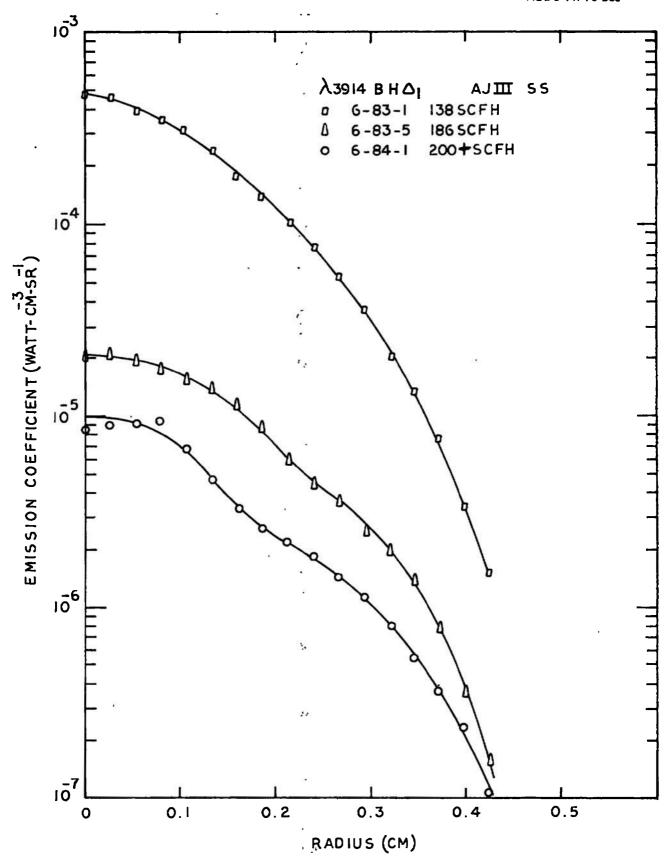


Fig. 20. Emission coefficients vs radius for the  $\lambda$  3914 BH $\triangle_1$  increment using arc jet III at three different gas flows.

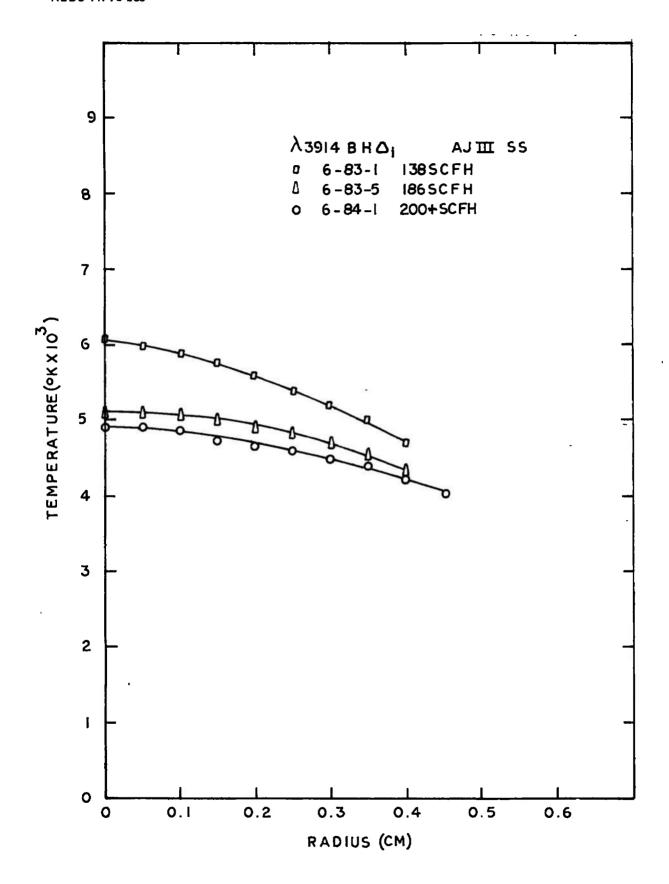


Fig. 21. Radial temperature profiles determined from the emission coefficient profiles of the \$\lambda 3914 \text{ BH} \times\_1 \text{ increment shown in Fig. 20.}

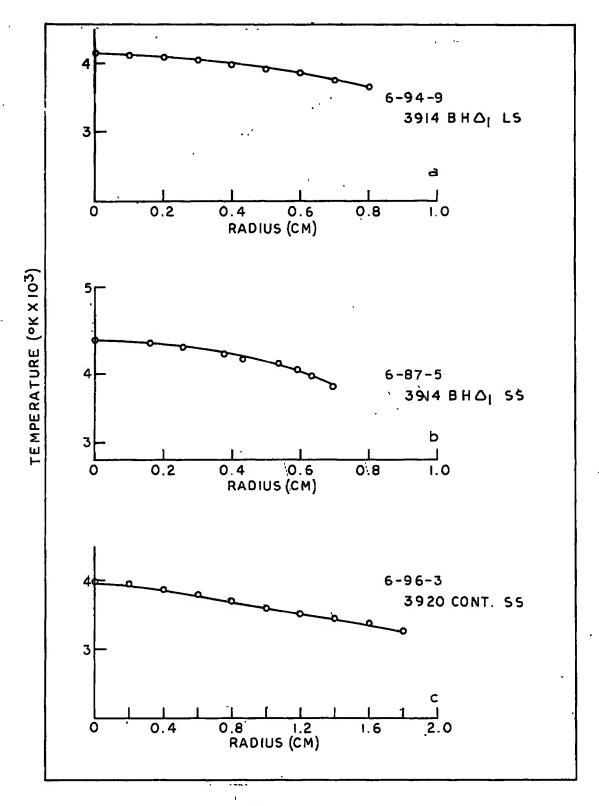


Fig. 22. Radial temperature profiles showing the low temperature limitations of the  $\lambda$  3914 BH $\Delta_1$  increment and the 28 Å increment of the  $\lambda$  3920 Cont.

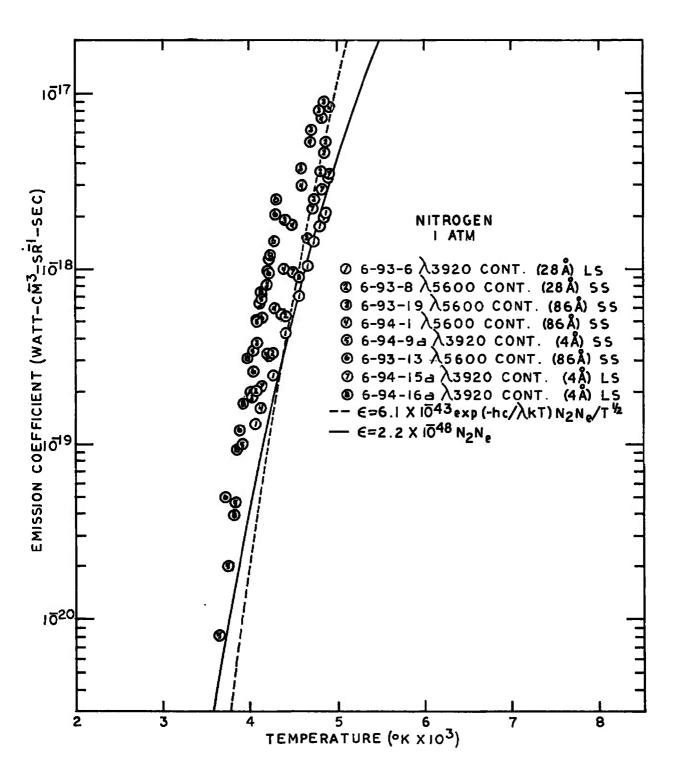


Fig. 23. Experimentally determined values of the continuum emission coefficient vs the temperature determined from the BH  $\triangle_1$  increment of the  $\lambda$  3914  $N_2^+$  band system.

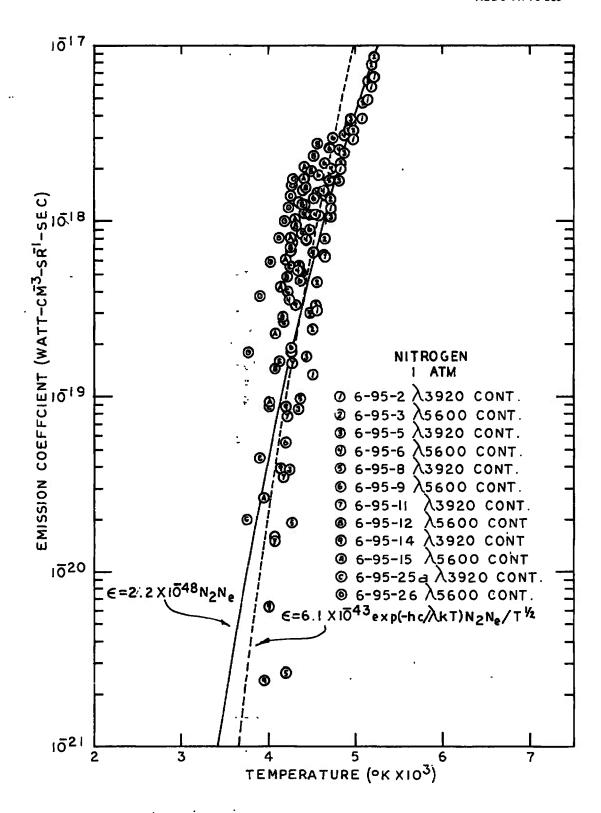


Fig. 24. Experimentally determined values of the continuum emission coefficient vs temperature determined from the BH $\Delta_2$  increment of the  $\lambda$  3914  $N_2^+$  band system.

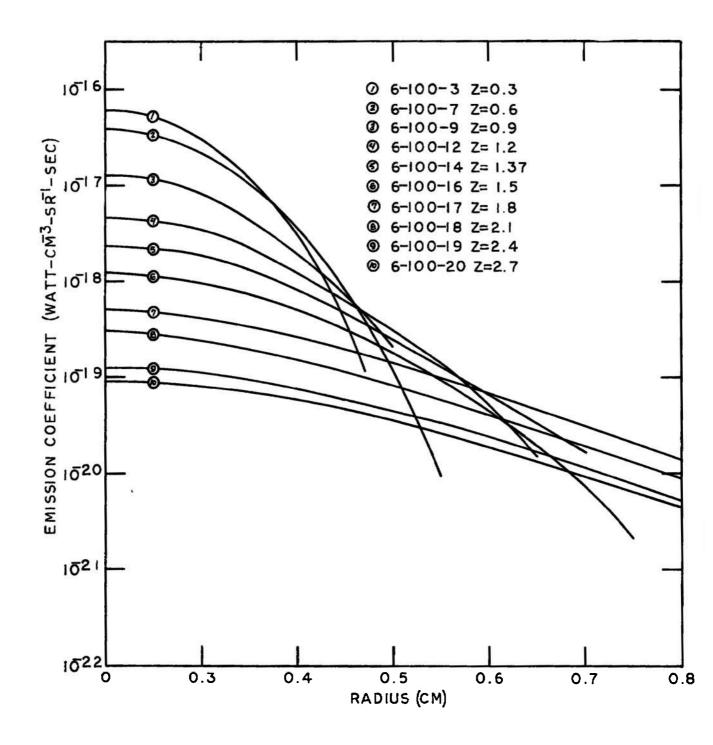


Fig. 25. Emission coefficient vs radius for the  $\lambda$  3920 continuum with Z as a parameter at a constant flow rate of 111 scfh in a nitrogen-oxygen plasma.

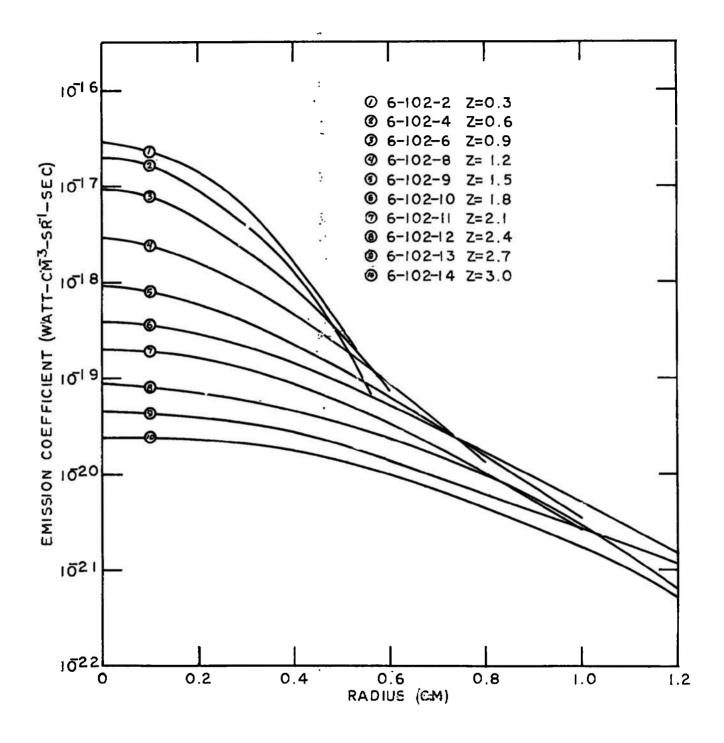


Fig. 26. Emission coefficient vs radius for the \$\lambda\$ 3920 continuum with Z as a parameter at a constant flow rate of 141 scfh in a nitrogen-oxygen plasma.

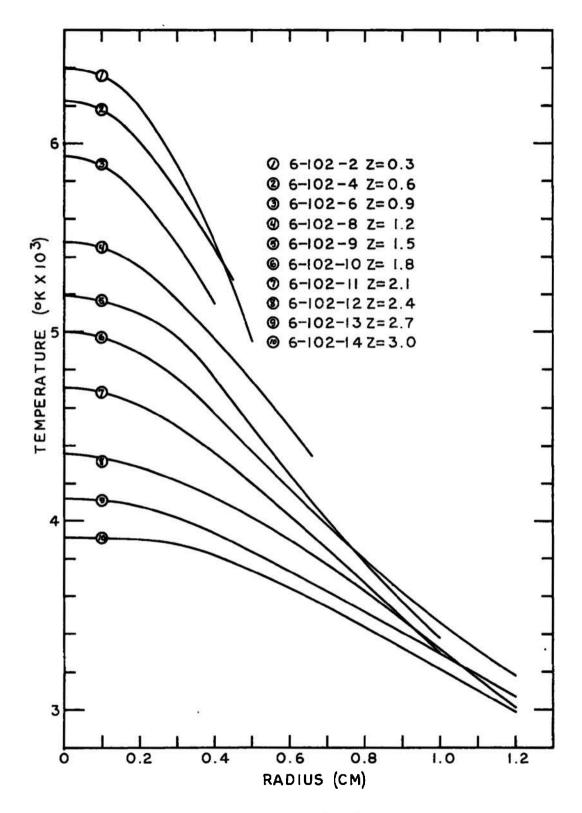


Fig. 27. Temperature vs radius for the nitrogen-oxygen plasmas determined from the data of Fig. 26 using the calibration curve of Fig. 23.

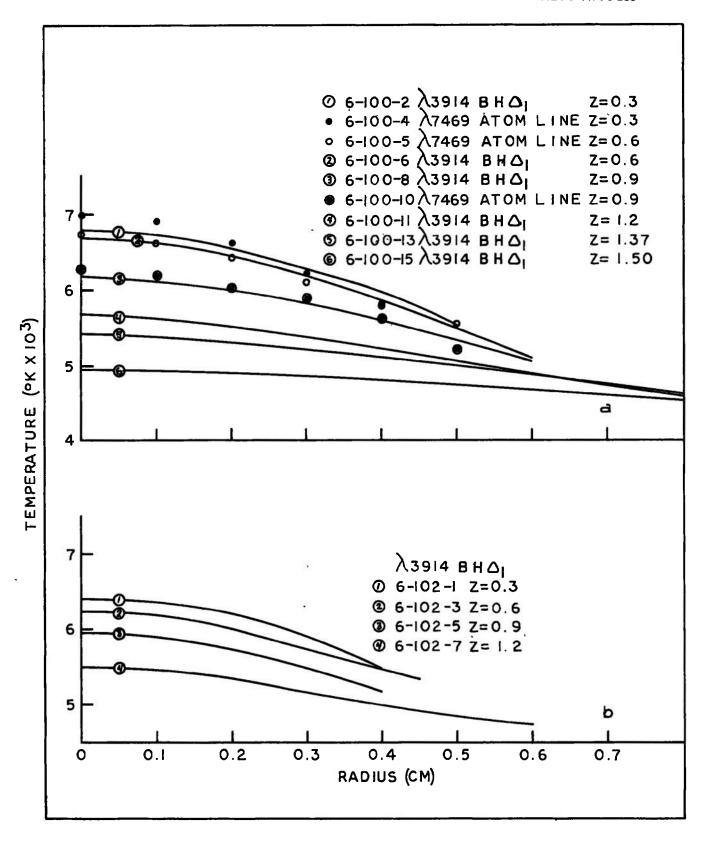


Fig. 28. Temperature vs radius for the two flow rates (a) 111 scfh and (b) 141 scfh in a nitrogen-oxygen plasma.

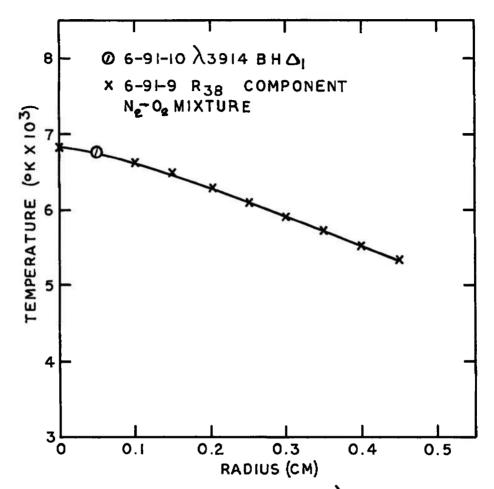


Fig. 29. Temperature vs radius for the \$\lambda 3914\$ band head increment and the \$R\_{78}\$ component of the neutral band; the solid curve labeled (1) is for the band head.

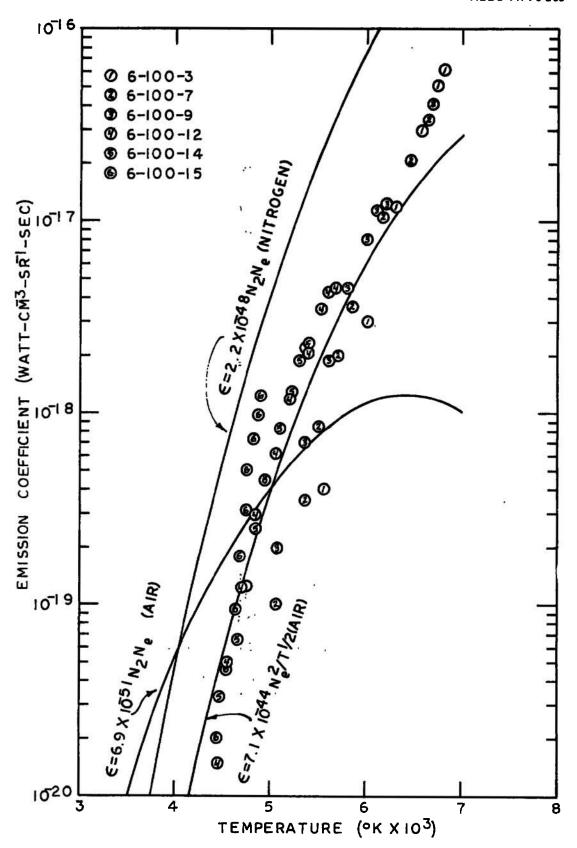


Fig. 30. Emission coefficient vs temperature for the \$\lambda\$3920 continuum at a flow rate of 111 scfh in a nitrogen-oxygen plasma; temperature determined from \$\lambda\$3914 BH\$\Delta\_1\$.

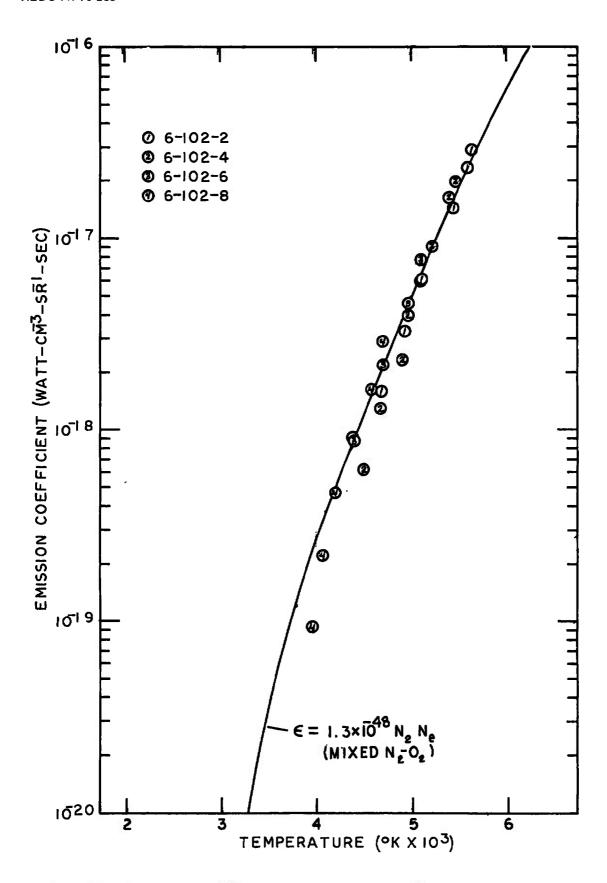


Fig. 31. Emission coefficient vs temperature for the \$\lambda{3920}\$ continuum at a flow rate of 141 scfh in a nitrogen-oxygen plasma; temperature determined from \$\lambda{3914}\$ BH\$\tilde{\Delta}\_1\$.

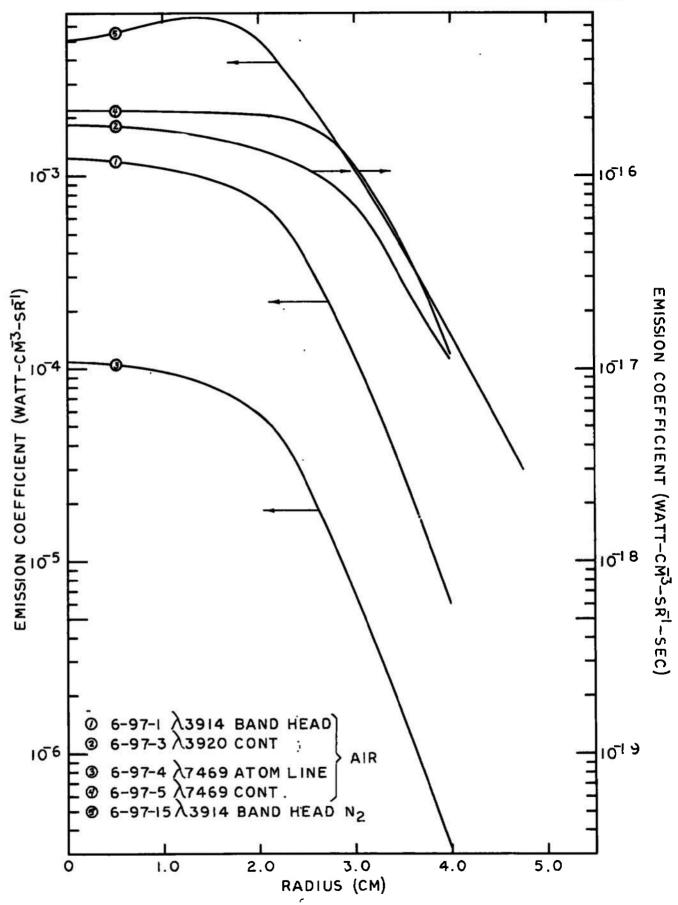


Fig. 32. Emission coefficient vs:radius for nitrogen and air in an rf plasma.

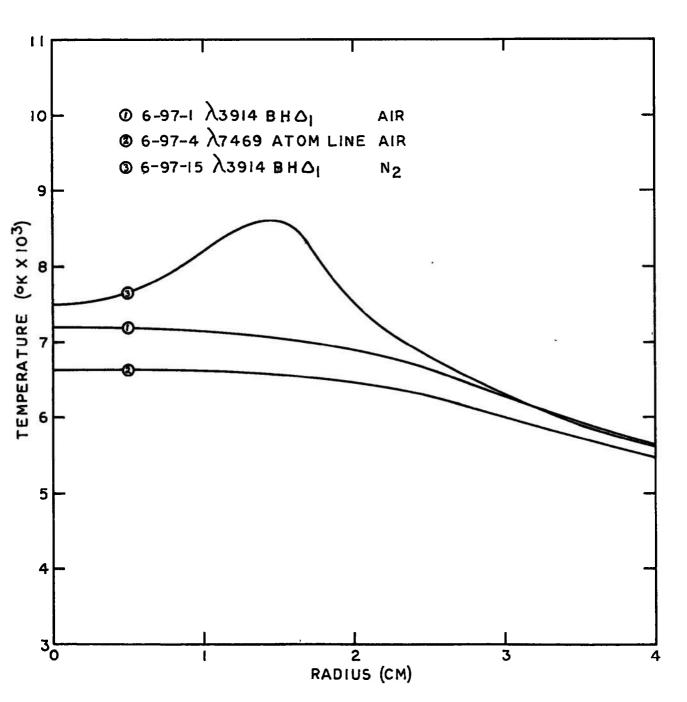


Fig 33. Temperature versus radius for nitrogen and air in an rf plasma.

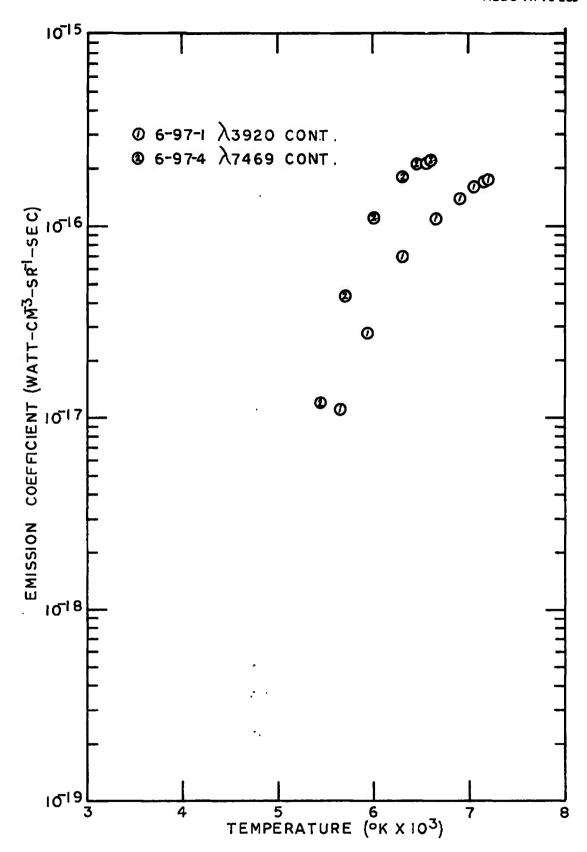


Fig. 34. Experimental continuum emission coefficient versus temperature using the corresponding band head increment and atomic line for reference in an rf air plasma.

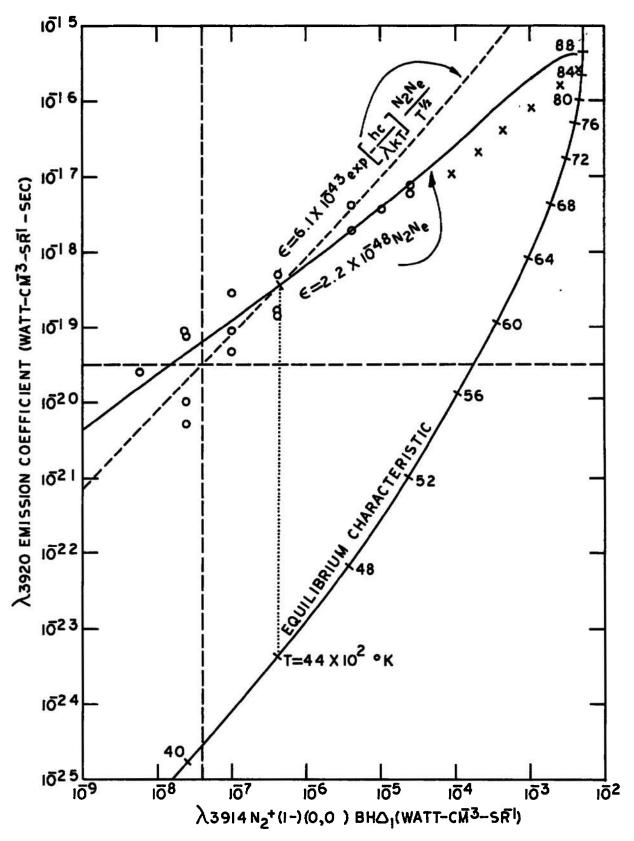


Fig. 35. Comparison of experimental data with equilibrium characteristic curve for 1 atm nitrogen plasma.



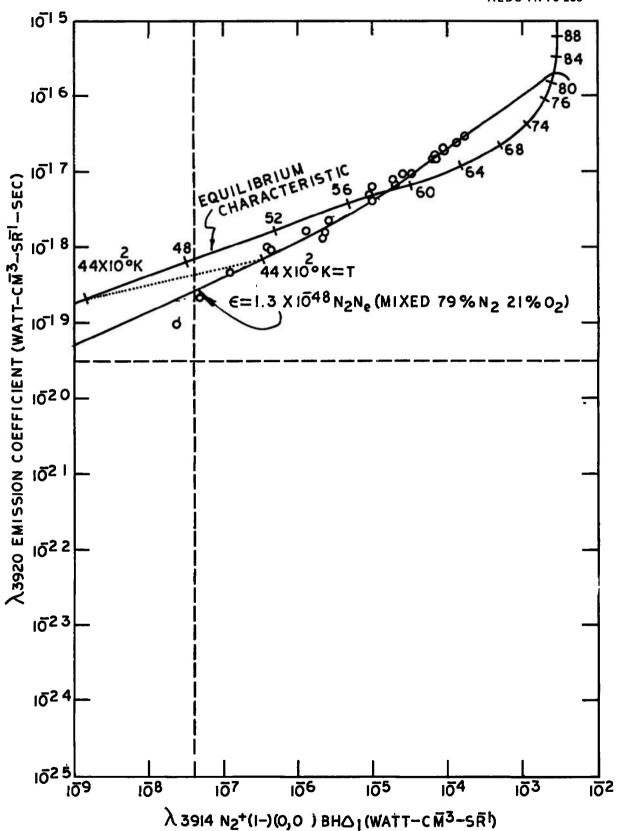


Fig. 36. Comparison of experimental data with equilibrium characteristic curves for 1 atm air and mixed nitrogen-oxygen plasmas.



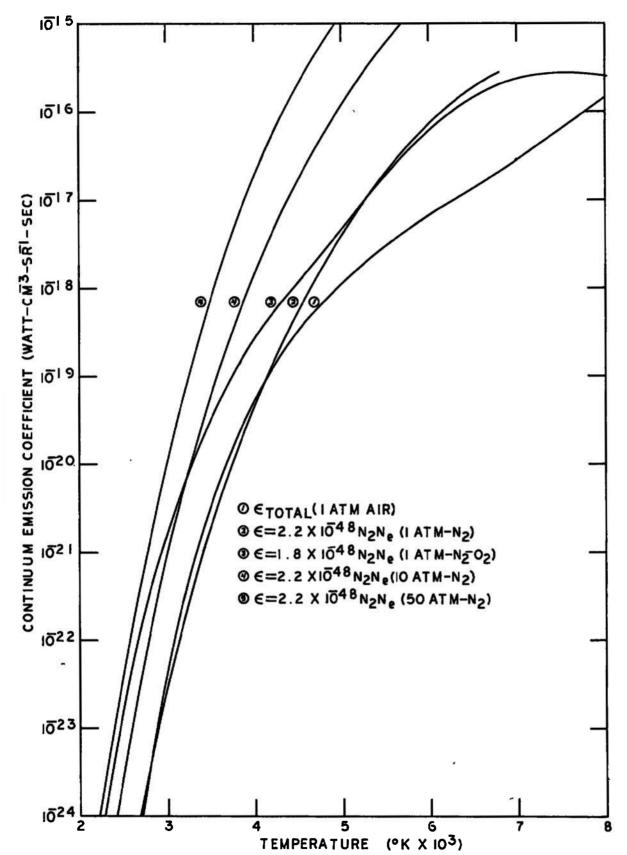


Fig. 37. Extrapolated calibration curves for  $\lambda$  3920 continuum for nitrogen, nitrogen-oxygen mixture and air plasmas.

TABLE I. PARTICLE NUMBER DENSITIES AND PARTITION FUNCTIONS USED IN ALL COMPUTATIONS.

		TVOIN T	• 11	TOTAL IN	CHIMIT DE	NOTITED.		222011 20	110110110			021110.10		
T	PARTITION						PAR	TICLE NU	MBER DEN	SITIES (	cm <sup>3</sup> )			
°K	FUNCTIONS		NITROGEN - 1 ATM			AIR-1 ATM								
	$U_2$	U2+	U <sub>o</sub>	N <sub>2</sub>	N <sub>2</sub> +	N_	N <sub>o</sub>	N <sub>e</sub>	N <sub>2</sub>	N <sub>2</sub> +	N_	N <sub>o</sub>	N <sub>e</sub>	0_
2000	4.312*	9.262	4.00	3.6718	1.4300	1.02-1	3.2909	1.4300	2.85	4.11 <sup>-7</sup>	1.73-8	2.9209	3.51 <sup>06</sup>	2.835
2400	5.59 <sup>2</sup>	1.223	4.00	3.06 <sup>18</sup>	2.7903	7.06-9	3,39 <sup>11</sup>	2.7903	2.3518	$1.12^{-2}$	6.65	1.98 <sup>11</sup>	4.9408	7.846 <sup>6</sup>
2800	7.05 <sup>2</sup>	1.56 <sup>3</sup>	4.00	2.62 <sup>18</sup>	6.31 <sup>05</sup>	5.44-5	9.11 <sup>12</sup>	$6.32^{05}$	1.9818	1.7001	1.1400	$7.94^{12}$	1.66 <sup>10</sup>	3.895 <sup>8</sup>
3200	8.69 <sup>2</sup>	1.96 <sup>3</sup>	4.00	2.29 <sup>18</sup>	3.72 <sup>07</sup>	5.55	1.0614	3.72 <sup>07</sup>	1.6618	4.33	2.79	$9.12^{13}$	$2.22^{11}$	6.0679
- 3600	1.05	2.43 <sup>3</sup>	4.00	2.04 <sup>18</sup>	8.88	1.2401	7.12 <sup>14</sup>	8.97 <sup>08</sup>	1.4018	3.48 <sup>05</sup>	$1.73^{04}$	$5.93^{14}$	$1.51^{12}$	3.788 <sup>1(</sup>
÷ 5000	1.25	2.98 <sup>3</sup>	4.00	1.83 <sup>18</sup>	1.12 <sup>10</sup>	9.3202	3.23 <sup>15</sup>	1.16 <sup>10</sup>	1.21 <sup>18</sup>	$1.33^{07}$	4.1005	2.6315	$6.27^{12}$	1.131 <sup>11</sup>
	1.47 <sup>3</sup>	3.61 <sup>3</sup>	4.01	1.66 <sup>18</sup>	8.8410	3.22 <sup>04</sup>	1.1116	9.63 <sup>10</sup>	1.0718	2.9208	5.0206	8.96 <sup>15</sup>	1.86 <sup>13</sup>	2.122
4400	1.47	4.33	4.02	1.50	4.78 <sup>11</sup>	6.22 <sup>05</sup>	3.05 <sup>16</sup>	5.80 <sup>11</sup>	9.64 <sup>17</sup>	4.0209	3.83 <sup>07</sup>	2.4716	4.4213	3.150 <sup>11</sup>
4800	1.70 <sup>3</sup>	5.14 <sup>3</sup>	4.05	1.34 18	1.90 <sup>12</sup>	7.6906	7.12 <sup>10</sup>	2.75	8.61 <sup>17</sup>	3.71 <sup>10</sup>	2.03 <sup>08</sup>	5.73 <sup>16</sup>	9.03 <sup>13</sup>	4.106 <sup>11</sup>
5200	1.96 <sup>3</sup>	5.14	4.05	1.54	5.84 <sup>12</sup>	6.64 <sup>07</sup>	1.44	1.08 <sup>13</sup>	7.49	2.47 <sup>11</sup>	8.13 <sup>08</sup>	1.16 <sup>17</sup>	1.6414	4.893 <sup>11</sup>
5600	$2.23^{3}$	$6.06^{3}$	4.08	1.17 <sup>18</sup>	5.84	4.21 <sup>08</sup>	2.57	3.59 <sup>13</sup>	6.18 <sup>17</sup>	1.24 12	2.5209	2.06 <sup>17</sup>	2.69 <sup>14</sup>	5.469 <sup>11</sup>
6000	2.523	$7.09^{3}_{3}$	4.11	9.66 <sup>17</sup>	1.43 <sup>13</sup>	4.21	2.57	1.06	4.22 <sup>17</sup>	4.67 <sup>12</sup>	6.40 <sup>09</sup>	3.24 <sup>17</sup>	4.08 <sup>14</sup>	5.700 <sup>11</sup>
6400	2.843	8,22 <sup>3</sup>	4.14	$7.40^{17}$	2.83 <sup>13</sup>	2.0109	4.05 <sup>17</sup>	1.06	4.22	1.31 <sup>13</sup>	1.33 <sup>10</sup>	4.51 <sup>17</sup>	5.94 <sup>14</sup>	5.710 <sup>11</sup>
6800	3.17	9.47	4.19	5.11 <sup>17</sup>	4.61 13	7.3009	5.66 <sup>17</sup>	2.61 14	$3.24^{17}$	1.31	1.33	4.51	5.94 14	5.710
7200	3.52 <sup>3</sup>	1.094	4.23	3.12 <sup>17</sup>	$6.23^{13}$	2.0610	7.05	5.79 <sup>14</sup>	1.97 17	2.62 <sup>13</sup>	2.5210	5.58 <sup>17</sup>	8.8714	6.045 <sup>11</sup>
7600	3.89 <sup>3</sup>	1.234	4.29	1.7117	7.17 13	4.6610	7.91 17	1.15	1.0817	3.82 <sup>13</sup>	4.5010	$6.24^{17}$	1.40 <sup>15</sup>	7.018 11
8000	$4.28^{3}$	1.404	4.35	8.71 16	7.36	8.87	8.25 <sup>17</sup>	2.0915	5.5216	4.41 13	7.63 <sup>10</sup>	$6.49^{17}$	2.26 15	5.944 11
8400	4.69 <sup>3</sup>	1.574	4.42	4.3610	7.05	1.4911	8.2311	3.53 <sup>15</sup>	2.75	4.4913	1.22 11	6.46 <sup>17</sup>	3.63 <sup>15</sup>	1.110 12
8800	5.13 <sup>3</sup>	1.764	4.49	2.2010	$6.53^{13}$	$2.60^{11}$	8.0117	5.6315	1.3816	4.2813	1.8411	6.25	5.66 <sup>15</sup>	1.415
9200	5.58 <sup>3</sup>	1.964	4.56	1.1510	5.95 <sup>1</sup>	3.35	7.6917	8.5915	7.2615	3.9813	3.2211	6.031	1.0416	1.79012
9600	6.063	2.184	4.64	6.13 <sup>15</sup>	5.3713	4.6211	7.3317	1.2616	3.92 <sup>15</sup>	3.64 <sup>13</sup>	3.63 <sup>11</sup>	5.75 <sup>17</sup>	1.25	2.21712
	6.57 <sup>3</sup>	2 414	4.72	3.37 <sup>15</sup>	4.8813	6.0811	6.95	1.79 <sup>16</sup>	2.18 <sup>15</sup>	3.31 <sup>13</sup>	4.77	5.4417	1.77	2.685

<sup>\*</sup> Superscript means power of 10.

### TABLE II A (10 pages)

COMPUTED NORMALIZED EMISSION COEFFICIENTS FOR INDIVIDUAL COMPONENTS AND SEXTET GROUPINGS OF THE N $_2(2+)(0,0)$   $\lambda$ .3371 Å BAND SYSTEM EMITTED BY A 1 ATM NITROGEN PLASMA

#### LEGEND

T	Equilibrium Temperature, °K
J	Upper rotational state quantum
	number for the R <sub>3</sub> branch component
	(E3) of the $^3\pi_2^{-3}\pi_2$ subband
LAMBDA	$\lambda_{o}$ of $R_{J}^{2}$ , single component (E3)
E1,E6	$\check{\mathcal{E}}_{\mathbf{J}}^{\mathbf{i}}$ , $\mathbf{cm}^{6}$ - $\mathbf{sr}^{-1}$ - $\mathbf{se}^{-1}$
ET	$\sum_{i=1}^{6}  \dot{\epsilon}_{J}^{i}, = \dot{\epsilon}_{J}^{*},  c_{m}^{-6} - s_{r}^{-1} - s_{e}^{-1}$

```
T =
        2000.0
           LAMDA
      0.3909710E-04
                         0.1215387E 14
                                                                                                     0.9894726E 14
0.1831751E 15
                                                               0.44197545 14
                                                                                  0.4259087E 14
                                            0.6944942E 15
      0,3909040E-04
                         0.1088086E 14
                                                              0.84698355 14
                                                                                  D.8164094E 14
      0.3908298E-04
                                                              0.49326045 14
                         0.3083461E 14
                                            0.2159432E 14
                                                                                  n.3895962E 14
                                                                                                     D.1317C466 1>
                                                              0.76568555 14
      0.3907533E-04
                         0.1976382E 14
                                            0.1524646E 14
                                                                                  0.74c5982t 14
                                                                                                     D.1856336E 15
      0.3906703E-04
0.3905841E-04
                                                              0.36202635 14
0.68200965 14
                         0.4783369E 14
                                            0.3897588E 14
                                                                                  0,3505426E 14
                                                                                                     0 · 1550654E
                                                                                                                   15
                         0,2785432E 14
                                            0,2351359E 14
                                                                                  0.6610441E 14
                                                                                                     0.18567335 15
      0.3904927E-04
                                            0.5460935E 14
0.3083855E 14
                                                              0.3199769E 14
0.5982277E 14
0.2785754E 14
                         0.6310351E 14
                                                                                  0,3104353E 14
                                                                                                     0.18075418 1>
      0.3903969E-04
                         0.3498451E 14
                                                                                  3.5889079E 14
                                                                                                     0.1637356⊨ 15
      0,3902956E-04
                         0.7626182E 14
                                            0,6818792E 14
                                                                                  0.27673836 14
                                                                                                     0.1993611E 15
      0.3901915E-04
                         0.4097102E 14
                                            0,3705088E 14
                                                              0.5169842E 14
                                                                                  0.5028402t 14
0.2326256t 14
                                                                                                     0.18006435 15
 11
      0,39008296-04
                         0.8698945E 14
                                            0,7938818E 14
                                                               0.2389889E 14
                                                                                                     0.21353011 15
      0.3899713E=04
0.3898499E=04
                         0.4567655E 14
0.9505197E 14
                                            0.42890996 14
                                                                                                     0.1746113# 15
                                                                                  0.1970084E 14
                                                                                                     0.22295701 15
                                            0,4564270E 14
0,9390179E 14
      0.3897267E-04
                         0.4903162E 14
                                                                                  0.3606744E 14
0.1644992E 14
                                                              0.3697875E 14
      0,3895996E-04
                                                              0.1685524E 14
                         0,1003905E 15
                                                                                                     0.22759758 15
                                            0,4792512E 14 0.3062588E 14
0,9714500E 14 0.1386450E 14
                                                                                  0,2990683E 14
0,1354651E 14
      0.3894675E-04
                                                                                                     0.1594799E 15
0.2275966E 15
                         0.5102213E 14
      0.3893309E-04
                         0.1030406E 15
      0.3891900E-04
                         0,5173126E 14
                                            D,4890366E 14
                                                              0.2504152E 14
                                                                                  0,2446061F 14
                                                                                                     0.1500876= 15
                                            0.1031591E 15
0.5117245E 14
      0.3890451E-04
                                                                                  0.1100479£ 14
0.1973797£ 14
      0,3888964E-04
                                                                                                     0.1397556E 15
      0.3887428E-04
                         0.1010002E 15
                                                                                  0.8821154E 13
                                                                                                     0.21913198 15
      0,3885833E-04 0,4958452E 14
                                                                                  0.1571760E 14 .0.1287276E 15
TUE
        2200.0
                                                  £2
      0,3909710E-04
                                                               0.1504357E 17 0.1449666E 17
                         0,3762943E 16. U,
                         0.3909040E-04
                                                                                  0,2799150E 17
                                                                                                     0.62243725 17
      0.3908298E-04
                                                                                  0.1345916E 17
                                                                                                     0.4364173E 17
                                           0.4731969E 16 0:2665952E 17
0.1211316E 17 0.1270741E 17
0.7319597E 16 0.2414008E 17
0.1/03175E 17 0.1142388E 17
                         0.6134092E 16
0.1486606E 17
                                                                                 0.2578593E 17
      0.3907533E-04
                                                                                                     0.6331142E 17
0.5199091E 17
                                                                                 0,1230428E 17
      0.3906703E-04
      0,3905841E-04
                                                                                  0,2339790E 17
                         0.8670839E 16
                                                                                                     0.63528416 17
      0,3904927E-04
                         0.1968096E 17
                                                                                  0.1108318E 17
                                                                                                     0.5921977E-17
                         0.1093479E 17
0.2389468E 17
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                                                                                  0,2092489E 17
0,9842003E 16
      0,3903969E=04
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      0,3902956E-04
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                        0,1287206E 17
0,2740865E 17
      0.3901915E-04
                                            0.1164044E 17
0.2501619E 17
                                                             0.1897171E 17
0.8859552E 16
0.1647927E 17
                                                                                  0.1845258E 17
0.8619725E 16
0.1605187E 17
                                                                                                     0.6193679E 17
      0,3900829E-04
                                                                                                     0.6990011E 17
                         0.1444014E 17
      0,3899713E-04
                                            0,1328127E 17
                                                                                                     0.6025256E 17
      0.3898499E=04
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                                            0.2791600E 17
                                                              0,7641902E 16
                                                                                  0,7448744E-16
                                                                                                     0.73162316 17
      0,3897267E-04
0,3895996E-04
                                                                                  0,1378057E 17
0,6353071E 16
                         0.1561461E 17
0.3210051E 17
                                            0.1453535E 17 0.1412863E 17 0.3002563E 17 0.6509644E 16
 14
15
                                                                                                     0.7498886E 17
                                                              0.1195896E 17
0.5475276E 16
0.9996011E 16
      0.3894675E-04
                         0.1638549E 17
                                            0.1539087E 17
                                                                                                    . 0.5541344E 17
 16
                                                                                  0.1167812E 17
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0,9771874E 16
                         0.3324360E 17
                                            0,3134147E 17
                                                                                                     0.7541001E 17
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      0.3891900E-04
                         0.1676166E 17
                                                                                                     0.5238418E 17
      0.3890451E=04
                         0.3361693E 17
                                            0,3189135E 17-
                                                               0,4548271E 16-- 0,4448541E- 16
                                                                                                     0:7490500E-17
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                                                                                                     0,4904234E 17
                                                                                                     0-17239814E-17
                                                                                                     0.4546554E 17
T =
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0.3580592E 19
                         0,4421153E 18
                                                               0.1912679E 19
                                                                                                     0.4197931E 19
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                                                                                                     0,7907666E 19
      0.3909040E-04
                         0.3962017E 18
                         0.1124447E 19
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                                                                                  0.3341027E 19
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0.3073472E 19
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                                                                                                     0,8131701E 19
                                                                                  0.1466355E-19
0.2789052E 19
      0.3904927E-04
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                                                                                                    · 0 . 7317633E 19-
                                            0.1141485E 19 0.2872230E 19
                                                                                                     0.8097716E 19
                         0.1294950E 19
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0.3267931E 19
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0,1176306E 19
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      0.3898499E-04
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                                                                                                     0.90573646-19
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0.9195444E 18
      0.3897267E-04
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                         0.1878194E 19
                                                                                                     0.7533850E 19
                                            0,3623858E 19
      0,3895996E-04
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0,3810939E 19
                                                                                  0.1664838E 19
0.7698510E 18
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0.7879304E 18
                         0.1984756E 19
0.4042235E 19
                                                                                                     0.7218753E 19
0.9410955E-19
      0.3894675E=04
      0.3893309E-04
                                            0.1935674E 19
                         0,2046416E 19
                                                              0.1452394E 19
                                                                                  0,1419821E 19
      0.3891900E-04
                                                                                                     0.9392301E-19
                         0.4121873E 19.
                                                                                  0.6527460E-18 -
      0.3890451E-04
                                           -0.3910299E 19
                                                               0.6673829E 18
                                           0,1964246E 19
                         0,2065056E 19
                                                              0.1223178E 19
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                                                                                                    0.6449411E 19
     0,3887428E-04 0.4118518E 19 0.3926845E 17 0.5588869E 18 0.5471484E 18 0.9151398E-19 0.3885833E-04 0.2044100E 19 0.1953210E 17 0.1018620E 19 0.9976696E 18 0.6013600E 19
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T =
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LAMDA .
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                                                                            E3
     0,3909710E-04 0,2468002E 20 0,
                                               0.1229195E 20
0.4398087E 20
0.3115231E 20
                           0,2212546E 20
     0.3909040E-04
     0,3908298E-04
                          0.6282961E 20
     0,3907533E-04
                                                                                                               0.4836025E 21
                          0,4038244E 20
     0,3906703E-04
0,3905841E-04
                                                                     0.1010944E 21
                          0.9807320E-20
                                                0.7991194E 20
                                                                                         0.9798670E 20 0.3769653E-21
                                                                                         0,1885518E 21 0,4888408E 21 0,9050707E 20 -0,4273120E 21 0,1732302E 21 0,4885484E 21 0,8263499E 20 0,4700053E 21
                          0.5734594E 20
                                                0,4840923E 20
                                                                    0.1945338E 21
                          0.1305437E 21
0.7277279E 20
                                               0.1129714E 21 0.9328990E 20
0.6414843E 20 0.1783970E 21
0.1427214E 21 0.8502800E 20
     0.3904927E=04
     0,3903969E-04
                          0.1596210E 21
     0,3902956E-04
                                               0.7808506E 20 0.1616172E 21 0.1635822E 21 0.7657230E 20 0.8995030E 20 0.1446925E 21
                                                                                         0,1571937E 21
                          0.8634708E 20
                                                                                                               0.4832431E 21
     0,3901915E-04
10
                          0.1847052E 21
0.9779921E 20
                                                                                         0.7453260E 20
                                                                                                               0.5043922E
     0,3900829E-04
     0.3899713E-04
                                                                                          0,1409388E 21
                                                                                                               1.4733838E 21
12
                                               0.1900944E-21
0.9955782E 20
                                                                     0,6816138E 20- 0,6643801E 20-0,5300378E 21
0,1280704E 21 0,1249126E 21 0,4594911E 21
     0,3898499E-04
                           0.2053460E 21
     0.3897267E=04
                          0.1069504E 21
                                                                   0.5999035E 20 0.5854697E 20 0.5467332E 21 0.1120922E 21 0.1094590E 21 0.4420257E 21
                                               0,2059458E 21
0,1067880E 21
     0.3895996E-04
0.3894675E-04
                          0.2212471E 21
0.1136894E 21
16
                          0.2322972E 21
0.1180072E 21
     0.3893309E=04
0.3891900E=04
                                                0,2190048E 21 0,5221821E 20-
                                                                                          -0.5101984E -20-
                                                                                                               0.5545401E
                                                0,1116210E 21 0,9704030E 20 0,9486358E 20
                                                                                                               0.4215321E 21
```

0.5235942= 26

0.41116158 26

0.5258754E 25

0.1012824E 26 0,9919756E 25

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LAMDA
                                                     Ë2
                                                                         E3
      0.3909710E-04
0.3909040E-04
                          0.7669660E 21
                                                                  0.37562635 22 0.36195766 22
                                                                                                          0.8142935= 22
                          0.6578051E 21
                                              0.3821147E 21
                                                                  0.73573905 22
                                                                                     0,7099272E 22
                                                                                                          0.15>26582 23
                                              0,1367887E 22
0,9695302E 21
                                                                                                          0.1058229= 25
                                                                  0.3590991E 22
      0.3908298E-04
                          0.1954118E 22
                                                                                     D.3469291E 22
                          0.1256793E 22
                                                                                     0.6759108E 22
0.3281572E 22
0.6353261E 22
      0.3907533E-04
                                                                  0.6988152E 22
                                                                                                          0.1597358= 23
                                              0,2489079E 22
                          0,3054763E 22
                                                                  0.3389220E 22
                                                                                                          3.1221473= 25
      D.3906703E=D4
      0.3905841E-04
                          0.1787956E 22
                                              0.1509323E 22
                                                                  0.6554843E 22
                                                                                                          0,16205388 23
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0,3492159E 32
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       0.3894675E-04
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                                           0,8553759E 33
                                                                                                                                                C.6821383E 33
                                                                                                                                                                                 0-3036567E 34
                                                                                                            0.1392835E 34
0.6930372E 33
          0.3894675E=04 · 0.4508098E 33
0.3893309E=04 0.9462281E 33
                                                                                                                                                                                  0-3627155E 54
                                                                                                                                                D,1360072E 34
                                                                                                                                                                                 0.3208448E 34
                                                                                                                                                0.6771108E 33
                                            0.4945652E 33
                                                                                                             0,13777315 34
                                                                              0,4677946E 33
                                                                                                                                                0.1346782E 34
                                                                                                                                                                                  3.3686873t 34
           0,3891900E-04
                                           -0:1030259E 34
                                                                            0,9773598E 33
                                                                                                              0.6839306E 33
                                                                                                                                                0,6689056E 33
                                                                                                                                                                                  0.3360455E-34
           0,3888964E-04 0,5347756E 33
                                                                            0,5086606E 33 0.1356529E 34
                                                                                                                                                0,1327370E 34
                                                                                                                                                                                 0.3727335E 34
          0.3887428E=04 0.1106966E 34 0.1055430E 34 0.6719075E 33 0.6577693E 33 0.3885833E=04 0.5712343E 33 0.5458245E 33 0.1329802E 34 0.1302398E 34
                                                                                                                                                                                 0.3492073F-34
                                                                                                                                                                                 0.37492598 34
             8600.0
Ť =
                   LAMDA
                                                                                        E2
    4 0.3907533E=04 0.1329220E 33
-5 0.3906703E=04 0.3254098E 33
6 0.3905841E=04 0.1921117E 33
-7 0.3904927E=04 0.422550E 33
        8800.0
7 =
 K LAMDA E1 E2 E3 E4 ET

1 0.3909710E=04 0.8037962E 32 0.4016289E 32 0.1331833E 34 0.1285084E 34 0.2729374E 34

2 0.3909040E=04 0.7229316E 32 0.4016289E 32 0.1331833E 34 0.1285084E 34 0.2729374E 34

3 0.3908298E=04 0.2062888E 33 0.1444023E 33 0.6769056E 33 0.6539522E 33 0.1681549E 34

4 0.3907533E=04 0.1334481E 33 0.1029458E 33 0.1373682E 34 0.1328631E 34 0.2938706E 34

5 0.3905841E=04 0.3267235E 33 0.2662195E 33 0.6957530E 33 0.6736609E 33 0.1962357E 34

6 0.3905841E=04 0.1929055E 33 0.1628426E 33 0.1407246E 34 0.1363939E 34 0.3126933E 34

7 0.394927E=04 0.444314E 33 0.3843454E 33 0.77104718E 33 0.6892615E 33 0.2228210E 34

8 0.3903969E=04 0.5581837E 33 0.2210824E 33 0.1432605E 34 0.1391078E 34 0.32479223E 34

10 0.3903969E=04 0.5581837E 33 0.2775040E 33 0.144924E 34 0.1410201E 34 0.344498E 34

11 0.3903829E=04 0.6681929E 33 0.6698608E 33 0.7278130E 33 0.7084060E 33 0.2714273E 34
       12
  16 0.3891900E-04
          0,3885833E=04 0,5857251E 33 0,5596706E 33 0,1402292E 34 0,1373394E 34 0,39210B2E 34
7 = /.9000,0
                                                                                                             E3 E4
-0.76546843E 33 -0.76308668E 33
                                                                                                                                                                                       ' FT
                   LAMDA
                                                                                        E2
                                                       E1
           0.3909710E-04 0.8005257E-32
                                                                           0,4000068E 32 0,1333953E 34 0,1287130E 34
           0.3909040E-04 0.7200119E 32
                                                                                                                                                                                 0-2733085E 34
                                                                           0.1438256E 33- 0.6782679E-33- 0.6552682E-33---0.1682827E 34
0.1025408E 33 0.1377045E 34 0.1331884E 34 0.2944392E 34
0.2651923E-33- 0.6977702E-33--0.6756139E 33 0.1964039E 34
0.1622289E 33 0.1411982E 34 0.1368529E 34 0.3134918E 34
        · 0.3908298E-04 · 0.2054649E-33
          0.3907533E-04 0.1329231E 33
         -0.3906703E=04 --0.3254627E 33
           0,3905841E-04 0,1921785E 33
                                                                            0,3829372E 33 0,7132044E 33 0,6919122E 33 0,2202989E 33 0,1438826E 34 0,1397118E 34
           0.3904927E=04
                                                                                                                                               0,69191221-33 0,2230558E
                                            0,4425043E-33
           0.3903969E-04
                                            0.2499183E 33
                                            0,5562811E -33- 0,4973822E-33-0,7246349E -33--0,7042221E-33--0.2482520E-34
          0-3902956E-04
        0.3911915E=04 0.3058685E 33 0.2765997E 33 0.1457725E 34 0.1417788E 34 0.3457981E 34 0.3958685E 33 0.6079742E 33 0.7321227E 33 0.7126006E 33 0.2718823E 34
  12 0,3899713E=04 0,3596747E 33 0.3308058E 33 0.1468842E 34 0.1430694E 34 0.3590016E 34 13 0;3898499E=04 0.7713735E-33 0,7140744E 33 0.7358269E 33 0.7172011E 33 0.2988476E 34 14 0.3897267E=04 0.4110279E 33 0.3826129E 33 0.1472601E 34 0.1436247E 34 0.3702489E 34
14 0.3897267E=04 0.4110279E 33 0.3820127E 33 0.1472601E 34 0.1436247E 34 0.3707487E 34 15 0.73895996E=04 0.8713311E 33 0.6149989E 33 0.7358798E 33 0.7181517E 33 0.3140361E 34 16 0.3894675E=04 0.4595661E 33 0.4316630E 33 0.1469193E 34 0.1434633E 34 0.3795055E 34 17 0.3893309E=04 0.799653829E 33 0.9101302E 33 0.1469193E 34 0.1434633E 33 0.3323523E 34 18 0.3891900E=04 0.5050062E 33 0.4776703E 33 0.1459061E 34 0.1426284E 34 0.3868022E 34 19 0.3890451E=04 0.1052954E 34 0.9988894E 33 0.7257986E 33 0.1426284E 34 0.3868022E 34 20 0.3888964E=04 0.5470727E 33 0.5203570E 33 0.1442606E 34 0.1411596E 34 0.3921631E 34 20 0.3888964E=04 0.5470727E 33 0.5203570E 33 0.1442606E 34 0.1411596E 34 0.3921631E 34 22 0.38887428E=04 0.5133545E-34 0.4108776E-34 0.7160822E 33 0.7010137E-33 0.3631411E 34 0.396403E 3
```

22 0.3885833E=04 0.5855577E 33 0.5595105E 33 0.1420348E 34 0.1391077E 34 0.3956493E 34

```
LAMDA
                                E1
                                                 E2
                                                                  E3
                                                                                   E4
                          0,7931240E 32
0,7133752E 32
                                                            0.6519044E 33 0.6281880E 33 0.1359405E 34 0.1328864E 34 0.1282161E 34 0.2721935E 34
          0.3909710E-04
                                           ο.
          0.3909040E=04
                                           0.3963198E 32
          0,3908298E-04
                           0.2035799E 33
                                           0.1425060E 33
                                                            0.6759212E 33 C.653CCC9E 33
                                                                                             v+1675018E 34
                          0.1317112E 33
0.3225186E 33
                                                                             0.1327827E 34
          0.3907533E-04
                                           0.1016059E 33
                                                            0.1372851E 34
                                                                                              0.2933995c 34
                                           0.2627933E 33
0,1607753E 33
                                                                             0,673846rE 33
0.1365554E 34
          0.3906703E=04
                                                            0,6959445E 33
                                                                                              0-19551025 34
                           0,1904565E 33
          0.3905841E-04
                                                            0.14059135 34
                                                                                              3.3125679E 34
                           0.4385835£ 33
                                           0,3795442E 33
                                                            0.7119808E 33
          0.3904927E-04
                                                                             0.69n725rE 33
                                                                                              0.22208532
                                                                             0,1395380E 34
          0.3903969E-04
                           0,2477325E 33
                                           0,2183722E 33
                                                            0,1437037E 34
                                                                                              0.329H521E 34
                                                            0.7240860E 33
0.1457350E 34
                                           0,4930959E 35
0,2742555E 33
          0.3902956E=04
                           0.5514873E 33
                                                                             0.703688FE 33
                                                                                              3-24/2358£ 54
                           0.3032763E 33
     10
         0.3901915E-04
                                                                             0.14174238 34
                                                                                              D.3452306E 54
                                                                             0,7127844E 33
0,1431820E 34
20
          0.3900829E-04
                           0,6605852E 33
                                           0.6029171E 33
                                                            0.7323117E 33
                                                                                              0:2708598E 34
                                                            0.1469999E 34
          0.3899713E-04
                           0.3567446E 33
                                            0,3281108E 33
                                                                                              0.3586674E 34
          0-3898499E=04
                                                                             0.718155eE 63
                           0.7652327E 33
                                           0.7083897E 33
                                                                                              0 -29285841 34
                                                            0.7368064E 33
          0.3897267E=04
                          0.4078380E 33
0.8647555E 33
                                                                             D.1438960E 34
                                           0.3796434E 33
                                                            0.1475383E 34
                                                                                              0.37018256 34
          0,3895996E-04
                                           0, F088484E 33
                                                                                              0-3:31214E 54
0:3797384E 54
                                                            0.7376913E 33
     15
                                                                             0.71991946 33
                                                                             0.1439006E 34
          0.38946756-04
                                           0.4285040E 33
                                                            0.1473672E 34
                           0.4562030E 33
                                           0,9036907E 33
                                                            0.7351450E 33
0.1465284E 34
                                                                                              0.3315638t 34
0.6873629t 34
                           0,9585526E 33
          0.3893309E-04
                                                                             0.7182500E 33
0.1432368E 34
          0.3891900E=04
                           0,5015630E 33
                                           0,4744134E 33
                                                            0,7293516E 33
                                                                             0.7133278E 33
          073890451E-04 -
                           0,1046061E 34
                                           0,9923498E 33
                                                                                              0-3481090H 34-
          0,3888964E-04
                          0,5436475E 33
                                                                                              0.3930759E 34
     20
                                           0,5170989E 33
                                                            0,1450598E 34
                                                                             0,1419415E 34
         0,3887428E=04 0,1126788E 34 0,1074328E 34 0,7205207E 33 0.7053586E 33 0,3885833E=04 0,5822513E 33 0,5563511E 33 0,1430108E 34 0,1400635E 34
                                                                                              0.3626995E 34
                                                                                              0.39693456 34
    7 =
            9400.0
                                                 E2
                                                                  E3
                                                                                   E4
                                          θ, -
         -0.3909710E=04
                          0.7820917E 32
                                                            0,6459421E 33 0.6224425E -33--0-1346594E--34
                                          C.3908178E 32 0.1317139E 34 0.1270906E 34 0.2697474E 34 0.1465335E 33 0.6702455E 33 0.6475175E 33 0.1659058E 34
         0.3909040E=04
                          0.7034715E 32
          0.3908298E-04
                          0,2007619E 33
          0.3907533E=04
                           0.1298952E 33
                                           0.1C02050E 33
                                                            0,1361866E 34
                                                                             0.1317202E 34
                                                                                              0.2909167F 34
          0,3906703E-04
                           0,3180937E 33
                                           0,2591879E 33
                                                            0.69065995 33
                                                                             0.6687291E 33
                                                                                              0.1936671E-34
                                           0,1585826E 33
                          0,1878591E 33
0,4326439E 33
                                                                             0.1355761E 34
          0,3905841E-04
                                                            0.1398810E 34
                                                                                              0:3101013E 34
                                          -0.3744042E 33
0.2154386E 33
          0.3904927E+04 ·
                                                            0,70718545-33-
                                                                             0.6860726E 33- 0-2200386E 34
                          0.2444045E 33
0.5441462E 33
         0.3903969E=04
                                                            0.1428004E 34 0.1386609E 34 0.7198700E 33 0.6995911E 33-
                                                                                              0.3274455E 34
0.2450139E 34
                                           -0.4665321E 33
          0.3902956E=04
         0.3901915E-04
                           0,2992806E 33
                                           0.2706421E 33
                                                            0,1449560E 34
                                                                             0.140984hE 34
                                                                                              0.3429329E 34
                          0.6519807E 33
0.3521561E 33
0.7555255E 33
                                           0.5950638E 33
0.3238906E 33
                                                                                              0.2685124E-34
         0.3900829E+04
                                                            0.7287563E 33
                                                                             0.70932368 33
         0.3899713E=04
--0.3898499E=04
                                           0.3238906E 33 0.1463603E 34 0.1425590E 34 0.6994035E 33- 0.7339823E 33- 0.7154028E 33-
                                                                                              0.35652406 34
                                                                                              -8-2904314E-34
         0.3897267E-04
                           0.4027421E 33
                                            0,3748998E 33 0,1470512E 34 0,1434209E 34
                                                                                             0.36823548 34
          0.3895996E-04
                           0,8541270E 33.
                                           0,7989070E-33 0,7356581E 33
                                                                             0.7179350E 33 · 0-3106627E 34-
          0.3894675E-04
                           0.4506953E 33
                                            0,4233307E 33
                                                            0.1470434E 34
                                                                             0.1435843E 34
                                                                                              0.3780303E 34
                                           0,8929895E 33 0,7339506E 33
                                                                             0.7170829E-33 -0.3291225E 34
          0.3893309E-04
                           0,9472018E 35
                           0.4957466E 33
                                          0,4689118E 33 0,1463763E 34
          0.3891900E=04
                                                                             0,1430880E 34 '0.3859381E 34
                          0.1034200E 34 0.9810985E 33 0.7290318E 33 0.7130148E 33 0.3457346E 34 0.5376317E 33 0.5113768E 33 0.145085E 34 0.1419663E 34 0.351524E 34 0.7210991E 33 0.7059246E 33 0.3604411E 34 0.7210991E 33 0.7059246E 33 0.3604411E 34
          -6:3896451E=64-
         0.3888964E-04
     20
         0.3867428E-04-
         0.3885833E-04 0.5761491E 33 0.5505203E 33 0.1432172E 34 0.1402657E 34 0.3961499E 34
    T =
            9600.0
                                          E2
                                E1
                                                                  E3
                                                                                   E4
                                                                                                    27
         0.3909710E=04-0.7675080E 32
0.3909040E=04 0.6903721E 32
                                                           -0.6368319E-33-0.6136635E-33-071327246E-34
                                          0.3908298E-04 -0.1970313E 33
                          0.1274882E 33
         0.3907533E=04
          0.3906703E=04-
                          0.3122200E 33
                          0.1844048E 33
         0,3905841E=04
          0-3904927E=04
                          0.4247280E-33
                          0,2399581E 33
         0.3903969E=04
         0.3902956E=04
                          0.53431028 33
                                           0.2657851E 33 0.1434368E 34 0.1395070E 34 0.3389133E 34 0.5844695E 33 0.7214595E 33 0.7622212E 33 ...0.2648523E 34
         0.3901915E=04
                          0.2939096E 35
                          0,6403732E 33
     0.3900829E=04
     22 0.3885833E-04 0.5672901E 33 0.5420553E 33 0.1426432E 34 0.1397034E 34 0.3952811E 34
    T = 9800.0
                                                 E2
      0.1802264E 33 0.1521394E 33 0.1358542E 34 0.1316733E 34
          0.3905841E-04
                                                                                              0.3007641E 34
          0.3904927E-04-
                           0.4151408E-33-
                                           0,3590572E-33 0,6873942E 33
                                                                             -0.4668720E-33-
                                                                                              0 (2128664E
                          0,2345654E 33 0,2067656E 33 0,1389220E 34 0,1348948E 34 0,3179499E 34 0,5223621E-33-0,4670544E-33-0,7009316E-33-0,6811859E-33-0.2371534E-34
          0.3903969E-04
         -0-3902956E-04
                          0,2873737E 33 0,2598746E 33 0,1412696E 34 0,1373992E 34 0,3333936E 34
     10 0.3901915E-04
         -0.3900829E-84- 0.6262200E-33--0.5715518E-33--0.7168811E 33--0.6919247E-33--0.2680578E 34
         0.3899713E=04 0.3383470E 33 0.3111898E 33 0.1429062E 34 0.1391949E 34
                                                                                              0.3470544E 34
                          0.7261433E 33 0.6722037E 33 0.7173602E 33 0.6992011E 33 0.2814908E 34 0.3872198E 33 0.3604505E 33 0.1438651E 34 0.1403134E 34 0.3589455E 34 0.8589455E 34 0.8589455E 34 0.8589455E 34 0.8589455E 34 0.8589455E 34 0.8589455E 34
          0.3898499E-04
         0.3897267E=04
     15 -0-3895996E-04
                          16 0.3894675E-04
                                                                                              0.3690237E 34
          -0-3893309E-04-
                                                                                              0.3195546E 34
                          0,4774542E 33 0,4516094E 33 0,1438159E 34 0,1405850E 34
0,9965291E 33 0,9453612E 33 0,7170874E 33 0,7013324E 33
0,5183160E 33 0,4930043E 33 0,1428727E 34 0,1398013E 34
                                                                                              0.3773072E 34
         0,38919005-04
                                                                                              0.3360310E 34
          0.3890451E-04-
                                                                             0,1398013E 34
                                                                                              0.3838060€ 34
      20
          0,3888964E=04
          22 0,3885833E-04 0,5560671E 33 0,5313314E 33 0,1413692E 34 0,1384557E 34 0.3885647E 34
```

T =

# TABLE II B (10 pages)

COMPUTED NORMALIZED EMISSION COEFFICIENTS FOR INDIVIDUAL COMPONENTS AND SEXTET GROUPINGS OF THE N $_2(2+)(0,0)$   $\lambda$  3371 Å BAND SYSTEM IN A 1 ATM AIR PLASMA

#### LEGEND

T	Equilibrium Temperature, °K
J	Upper rotational state quantum number for the $R_3$ branch component (E3) of the $3\pi_2$ $^3\pi_2$ subband
LAMBDA	$\lambda_{_{f 0}}$ of ${ t R}_{f J}^2$ , single component (E3)
E1,E6	$\in^{*i}_{J}$ , $\operatorname{cm}^{6}$ - $\operatorname{sr}^{1}$ - $\operatorname{sec}^{1}$
ET	$\sum_{i=1}^{6}  \boldsymbol{\epsilon}_{J}^{*i},  \boldsymbol{\epsilon}_{J}^{*},  \mathbf{cm}^{6} - \mathbf{sr}^{-1} - \mathbf{sec}^{-1}$

```
2000.0
T =
                                                                                F2
                                                                                                    0.1274941E 08 0.1228594E 08
                                       0.3505956E U7
                                                                                                                                                               0.28541318 08
         0.3909710E-04
                                                                    0.
                                                                      0.1743750E 07
                                                                                                    0.2440648E 08
          0.3909040E-04
                                       0,313874UE U7
                                                                                                                                  0.23550496 08
                                                                                                                                                                 0.5283946E 08
          0.3908298E-04
                                        0.8894681E 07 0.6226304E 07
                                                                                                    0.1163262E 08
                                                                                                                                  0.11238525 08
                                                                                                                                                                 0.3799212E 08
                                                                                                   0.2208729E 08 0.2136361E 08
0.1044316E 08 0.1011190E 08
0.1967354E 08 0.1906876E 08
0.9230188E 07- 0.8954948E 07
                                                                                                                                                                0.5355011E 08
0.4559652E 08
                                       0.5701154E U7
                                                                      0.4398058E 0/
          0.3907533E-04
                                     0.1379831E 08 0.1124315E 08 0.8034976E 0/ 0.6782831E 07 0.1820311E 08 0.1575285E 08
          0.3906703E-04
                                                                                                                                                                 0.5356010E 08
          0.3905841E-04
                                                                                                                                                               -0.5214109E 08
         -0.3904927E-04
                                                                                                   0.1725673E 08 0.1675712E 08 0.8035904E 07 0.7809832E 07
                                                                      0.8895819E 07
        0.3903969E=04
                                        0.1009178E U8
                                                                                                                                                                 0.5300144E 08
                                                                      0,1966978E 08
         0,3902956E-04
                                        0,2199881E-08
                                                                                                                                                                 0.5751432E 08
                                                                                                   0.1491314E 08
0.6893975E 07
0.1270189E 08
                                                                                                                                                                 0.5192481E 08
0.6159579E 08
0.5036911E 08
         0.3901915E-04
                                                                                                                                  0.1450514E 08
                                       0.1181867E UB
                                                                      0.1068785E 08
                                                                      0,2290065E 08
                                                                                                                                  0.6710417E 07
0.1237252E 08
                                       0.2509075E 08
0,1317605E 08
          0,3900829E=04
          0,3899713E-04
                                                                      0.1211865E UB
         -013898499E=04--012741909E-08 -012538272E 08
                                                                                                   0.5830328E 07
                                                                                                                                  0.5682987E U7
                                                                                                                                                                 0.6431513E 08
                                       0.1414387E 08
                                                                      0.1316629E 08
         0.3897267E-04
                                                                                                   0.1066705E 08
                                                                                                                                                                 0.4838137E 08
                                                                                                                                  0.10404175 08
                                                                     0.2708731E 08
0.1382468E 08
        0.3895996E-04
                                       0,2895908E 08
                                                                                                    0.48621355 07
                                                                                                                                  0.4745214E 07
                                                                                                                                                                 0.6565373E OH-
                                                                                                   0.8834470E 07
0.3999411E 07
         0.3894675E+04
                                       0.1471806E-08
                                                                                                                                  0.86270518 07
                                                                                                                                                                 0.4600426E 0B
                                                                                                                                  0.39076838 07
                                                                                                                                                                 0.6565347E 08
                                                                      0.2802286E 08
         -0,3893309E=04
                                        0,2972352E 08
                                                                      0.1410696E 08
                                                                                                   0.7217814E 07 0.7056011E 07
                                                                                                                                                                 0.43294758 08
                                       0.1491396E UB
        0.3891900E=04
                                                                                                  0.3245639E 07-0.3174490E 07-0.6440824E-06-0.5818488E 07 0.5693698E 07 0.4031449E 08 0.2599150E 07 0.4533966E 07 0.3713390E 08
         0:3890451E-04-0-2975772E-08-0.2823039E-08
 20 0.3888964E=04 0.1476142E U8 0.140408BE 08
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-0.3893309E-04 0.4043110E 11
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	10	0.3901915E-04	0,9628485E 15	0,8707196E 15	0.1802179E:16 -0.8538508E:-15	0,1752853E 16	0.5388600E 10 0.5624432E-16
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	-21	0:3887428E-04	-0:2678781£-16-	·0 - 2554108E-14		-074181801E-15-	
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0.3909040E+04
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 22 0.3885833E-04 0.4824487E 30 0.4609901E 30 0.8251471E 30 0.8081496E 30 0.2576736E 31
        5800.0
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           LAMDA
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10 0,3901915E-04
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             0.3891900E=04 0.1446343E 32 0.1368056E 32
0.3890451E=04 0.3000311E-32 0.2846266E 32
  22 0,3885833E-04 0.1640502E 32 0.1567533E 32 0.3149682E 32 0.3084791E 32 0.9442507E 32
7 =
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                                                                           42E- 31 ... 0 .
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                                                                                                                                                                               0.6981133E 32 0.1556594E 33
0.3515877E 32 0.1057196E 33
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5-0.3906703E-04
                                                                                                                                        0,7293483E 32 0,7069056E 32 0,1641460E 33
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 0.7092188E 32 0.1772917E 33
0.3534062E 32 0.1446257E-33
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                                                                                                                                       0.7106811E 32 0.6931398E 32 0.1854144E 33

...0.3517604E 32 0.3432878E 32 0.1876486E 33

0.6954527E 32 0.6790967E 32 0.1876486E 33

0.3432628E 32 0.3353758E 32 0.1730607E 33
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         0.3908298E=04
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0,7791150E 32
                              0.1434974E 33
0.7545615E 32
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                                                                         0.1062174E 33
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        0,3894675E-04
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0.8237006E 32
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0,3891900E-04
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0.2056848E 33
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        0,3907533E-04
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        0,3903969E-04
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0,8818227E 32 0,8110448E 32
        0:39008296=04
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0:3215709E 33
        0,38984992=04
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0,3030881E 33
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0.3021172E 33
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                              0:2534147E 33
        0.3888964E-04
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                                                                                              0,2956238E 33
                                                                                                                    0.8537916E 33
        -0;3887428E-04***0,2709675E-33***0;2583525E-33***0;1488399E-33***0;1457084E-33***0;8238684E-33***0;3885833E-04***0;1394663E-33***0;1332627E-33***0;2929618E-33***0;2869254E-33***0;8526161E-33***
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	3	-0,3908298E=04	0,6886467E 32	0,4820532E 32	0.2146935E 33	0.2074138E 33	0.53917728 33
	4	0.3907533E-04	0,4452565E 32	0,3434841E 32	0.4340794E 33	0,4198442E 33	0.9327976E 33
	5	07,39067036=04	0.1089431E 33	-0,8876864E 32	0,2190158E 33-	-0,2120619E 33-	
	6	0.3905841E-04	0.6427321E 32	0,5425674E 32	0.4412382E 33	0,4276602E 33	0,9874284E 33
	7	7.3904927E-04	7714784912 33	0,12794328 33	-0", 221 0593E 33-	0.21523638 33	0,7128840E-33
	8	0.3903969E-04	0.8340457E 32	0,7351981E 32	0.4454823E 33	0,4325698E 33	0.1034977E 34
	9	0.3902956E-04	0.1854070E 33	0.1657762E-33	0.22327448 33	0.2169853E:33	-0.7914429E-33
	10	0.3901915E-04	0,1017992E 33	0,9205802E 32	0.4469220E 33	0,4346788E 33	0.1075458E 34
92	11	073900829E-04	0.2213511E 33	0.2020276E 33	0.2233138E 33	0.2173597E 33	0.8640522£ 33
	12	0,3899713E-04	0.1193133E 33	0.1097368E 33	0,4456783E 33	0.4341046E 33	D.1108833E 34
	13	0,3898499E+04	-D.2554084E-33-	0 <del>,2364364E-</del> 33	70.2220630E 33"	0.2164425E-35-	-0:9303502 <del>E</del> -33
	14	0.3897267E-04	0.1358224E 33	0,1264329E 33	0.4419559E 33	0.4310466E 33	0.11352 <i>5</i> 8E 34
	15-	-073895996E-04	0,2873099E 33-	0 <del>-2</del> 687354E-33	0.2196005E 33-	0.2143107E 33	- p. 9899566E-33
	16	0.3894675E-04	0.1511893E 33	0.1420098E 33	0.43589g6E 33	0,4256383€ 33	0.1154728E 34
		-0.3893309E-04	073168225E 33	0,2986898E 33	0.2160237E 33	0+2110597E-33-	-0:1042596E34
	18	0,3891900E-04	0.1653083E 33	0,1563604E 33	0.4276963E 33	0.4180897E 33	0.1167455E 34
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	20	0.3888964E-04	0.1780822E 33	0,1693860E 33	0.4175727E 33	0,4085977E 33	0,1173639E 34
	-21-	-073887428E-04	0.3678834E 33-	-0,3507565E 33	0.2059293E 33	0,2015966E33-	-071126166E-34
	22		0.1894417E 33	0,1810151E 33	0,4057524E 33	0,3973918E 33	0.1173601E 34

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0.8633613E 32 0.6043536E 32
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            0.3907533E-04
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14.	0.3897267E-04	0.2254213E 33	0.2098377E 33	0.7639053E-33	0.7450481E 33	0.1944212E 34
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        0.3885833E=04 0.3800630E 33 0.3631566E-33 0.9662360E 33 0.9463224E 33 0.2655779E 34
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## TABLE III A (14 pages)

COMPUTED NORMALIZED EMISSION COEFFICIENTS FOR INDIVIDUAL COMPONENTS AND QUARTET GROUPINGS OF THE N $_2^+(1-)(0,0)$   $\lambda$  3914  $_{\rm A}^{\rm o}$  BAND SYSTEM IN AN ATMOSPHERIC PRESSURE NITROGEN PLASMA

#### LEGEND

T	Equilibrium Temperature, oK
K	Upper rotational quantum number for R branch component (E2) of the $2\sum_{1}^{2}\sum_{1}^{2}$ subband
LAMBDA	$\lambda_{0}^{0}$ of $R_{K'}^{1}$ band component (E2) $A$
E1E4	€*i cm <sup>6</sup> -sr <sup>1</sup> -sec <sup>1</sup>
ET	$\sum_{i=1}^{l_{1}} \epsilon_{K'}^{*i} = \epsilon_{K'}^{*} c_{m}^{-6} - s_{r}^{-1} - s_{c}^{-1}$

T =	2000.0							
J67890123456789012345678901234567890123456	LAHOA 0.3357080E-04 0.3355950E-04 0.3355950E-04 0.3355950E-04 0.33535950E-04 0.335352290E-04 0.3352290E-04 0.334680E-04 0.3348280E-04 0.334910E-04 0.334910E-04 0.334910E-04 0.334910E-04 0.334910E-04 0.334910E-04 0.3324910E-04 0.3337540E-04 0.3337540E-04 0.3328700E-04 0.3328700E-04 0.3328700E-04 0.3328700E-04 0.332870E-04 0.3312980E-04 0.3312980E-04 0.33129810E-04 0.3329310E-04 0.3329310E-04 0.3329310E-04 0.3329310E-04 0.3329310E-04 0.3329310E-04 0.3329310E-04	10.24457493E 14 0.2447397E 14 0.2447397E 14 0.2447397E 14 0.2457598E 14 0.2349737E 14 0.2349731E 14 0.223594E 14 0.223594E 14 0.223594E 14 0.223594E 14 0.2153499E 14 0.194545E 14 0.194545E 14 0.194545E 14 0.194545E 14 0.194545E 14 0.1943454E 14 0.11330498E 14 0.11330498E 14 0.11330498E 14 0.11330498E 14 0.11330498E 13 0.8946422E 13 0.8946422E 13 0.8946622E 13 0.8946622E 13 0.3057884E 13 0.4076886E 13 0.3272806E 13 0.2041108E 13 0.2041108E 13 0.2041108E 13 0.2041108E 13 0.2041108E 13	22	- 2444931	L4  0.15516>6  14  0.1366340L  14  0.1366340L  14  1.175993L  13  1.11024>2= 14  1.11024>2= 14  1.11024>2= 14  1.11024>2= 14  1.11024>2= 14  1.11024>2= 13  0.86515)*£  13  0.86515)*£  13  0.86609098E  13  0.491822L  13  0.491822L  13  0.491822L  13  0.491822L  13  0.491822L  13  0.1167200L  13  0.2533372L  13  0.2533372L  13  0.1167200L  13  0.1173218L  13  0.1173	F)  0.1413249 to 14  0.1325170t 14  1.12305225 14  1.12305225 14  1.12305225 14  1.12305225 14  1.12305225 14  1.1230525 15  0.4426910t 13  0.4426910t 13  0.448060635 13  0.448060635 13  0.48060635 13  0.483237 15  0.483247 13  0.3440025 13  0.3440025 13  0.3440025 13  0.3440025 13  0.3440025 13  0.3440035 13  0.3440035 13  0.12415016 13  0.12415016 13  0.12415016 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.12516645 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 13  0.1251665 1	## 14	7   1   1   1   1   1   1   1   1   1
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53 54 55 56	0;3287629E=04 0;3284760E=04 0;3281829E=04 0;3278819E=04	0.5573829E 32 0.5561867E 32 0.5446932E 32 0.5329453E 32	0.5565833E 32 0.5457911E 32 0.5346976E 32 0.5233308E 32	0.5463197E 32 0.5355184E 32 0.5249079E 32 0.5137154E 32	0.3378773= 32 1.527802?= 52 0.3139157= 52 0.5022273= 52	0.33504176 52 J.32120266 32 0.30454525 52 J.29407556 32	0.3292457E 32 0.3166779E 32 0.3052413E 32 0.2939858E 32	g.2567191E 53 ).2601279E 53 d.2535gg4E 33 g.2464478E 33
T ■ J 16	7000,0 LAMOA 0,3357080E=04	51 0.6100503E 32	62 0.5738789£ 32	E3 g.54075955 32	€4 a.8812772∈ 37	E5 g.a5j5116- 32	=6 J.93061276 {2	¢ſ ].429.394E {S
17 18 19 20 21	0,3355950E-04 0,3354760E-04 0,3353550E-04 0,3352290E-04 0,3350990E-04	0.6365102E 32 0.6617855E 32 0.6859119E 32 0.7085828E 32 0.7303636E 32	0.6265773E 32 0.6265773E 32 0.6511079E 32 0.6743965E 52 0.6964085E 32	0.5673201E 32 0.59343*3E 32 0.6183492E 32 0.6420423E 32 0.6544838E 32	0.48381856 52 0.9851152E 32 0.98515476 32 0.98408056 32 0.38482656 52	j.d54682:= {2 g.d6j624gE 32 j.861724gE {2 j.d6j8548= 52 g.8592374= 32	).4343704E 52 ŋ,9364365E 32 ŋ,8364365E 32 ŋ,8382975E 32 ŋ,8373091E 52	] • 459 .545E 33 g • 446 4446E 53 g • 45379 + g £ 33 g • 45379 + g £ 33 g • 4569325E 33
22. 23 24 25 26 27	6,334905GE-04 0,3348280E-04 0,3345860E-04 0,3345410E-04 0,3343910E-04 0,3342380E-04	0.75j2310E 32 0.7690565E 32 0.7865425E 32 0.8026586E 32 0.8174158E 32 0.8307905E 32	0.7171198E 32 0.7365015E 32 0.7545546E 32 0.7712486E 32 0.7665928E 32 0.8035636E 32	9.64563932 32 0.7054874E 32 0.7240239E 32 3.7412176E 32 3.7570758E 32 0.7714742E 32	0.8744593E 32 0.8740167E 32 0.8685303E 32 0.8620912E 32 0.85463335E 32 0.8463013E 32	0.4564971: 52 0.4526724: 52 0.4478164: 52 0.8419555: 52 0.8591513: 52 0.8274256: 52	0.835167]E 32 0.8319349E 32 0.827679E 32 0.422398E 32 0.8161759E 32 0.90284E 32	].4/231156 43 J.4769560E 33 J.480J1425 33 J.4841551E 33 J.4985642E 33
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LAMDA

## TABLE III B (14 pages)

COMPUTED NORMALIZED EMISSION COEFFICIENTS FOR INDIVIDUAL COMPONENTS AND QUARTET GROUPINGS OF THE N $_2^+(1-)(0,0)$   $\lambda$  3914  $\mathring{\rm a}$  BAND SYSTEM IN AN ATMOSPHERIC PRESSURE <u>AIR</u> PLASMA

## LEGEND

T	Equilibrium Temperature, °K
<b>K</b> .	Upper rotational quantum number for R branch component (E2) of the $2\sum_{1}^{2}\sum_{1}^{2}$ subband
LAMBDA	$\lambda_0$ of $R_{K'}^1$ band component (E2) $\mathring{A}$
E1,E4	$\epsilon^{*i}_{K'}$ cm <sup>6</sup> -sr <sup>1</sup> -sec <sup>1</sup>
ET	$\sum_{i=1}^{k} \epsilon_{K'}^{*i} = \epsilon_{K'}^{*} c_{m}^{-6} - s_{r}^{-1} - s_{c}^{-1}$

J LAMOA  16 0.3357080E-0  17 0.3355950E-0  18 0.33554760E-0  19 8.3353550E-0  20 0.335290E-0  21 0.335290E-0  22 0.3349650E-0  23 0.3348280E-0  24 0.3344380E-0  25 0.3344380E-0  26 0.3343910E-0  27 0.334541E-0  28 0.3343910E-0  30 0.3335860E-0  31 0.3335860E-0  32 0.3337540E-0  33 0.3337540E-0  34 0.3332360E-0  35 0.3328700E-3  36 0.3328700E-3  37 0.332870E-0  48 0.3318910E-0  49 0.3316840E-0  40 0.3316840E-0  41 0.3316840E-0  42 0.3312950E-0  44 0.331580E-0  45 0.330810E-0  46 0.330810E-0  47 0.330810E-0  48 0.3318910E-0  50 0.329380E-0  50 0.329380E-0  50 0.329380E-0  50 0.329380E-0  50 0.329380E-0  50 0.32887620E-0  50 0.32887620E-0  50 0.3288810E-0	0.19:0157E 14 0.19:0157E 14 0.19:2619E 14 0.19:06081E 14 0.19:06081E 14 0.19:06081E 14 0.19:06081E 14 0.18:0612E 14 0.18:0612E 14 0.17:266203E 14 0.16:06081E 14 0.12:06081E 14 0.12:06081E 14 0.12:06081E 14 0.12:06081E 14 0.12:06081E 14 0.12:06081E 14 0.10:06081E 13 0.10:06081E 13 0.52:06081E 13	0.1799753E 14	6.5 0.1665800E 14 0.1692592F 14 0.17737342E 14 0.1774123E 14 0.1774123E 14 0.1763174E 14 0.1667451E 14 0.1657451E 14 0.1657451E 14 0.1657451E 14 0.1539279E 14 0.1639270E 14 0.1374432E 14 0.1437670E 14 0.1374432E 14 0.129562E 14 0.1193626E 14 0.1193626E 14 0.1193626E 13 0.8155300E 13 0.8155300E 13 0.87564653E 13 0.87564653E 13 0.696556E 13 0.5419765E 13 0.4109765E 13 0.4109765E 13 0.4109765E 13 0.4109765E 13 0.327218E 13 0.327218E 13 0.327218E 13 0.327218E 13 0.327218E 13 0.2173885E 13 0.2173885E 13 0.2173885E 13 0.2173885E 13 0.2173885E 13 0.2173885E 13 0.2173885E 13 0.2173885E 13 0.2173885E 13 0.1723879E 13	0.125049E 14 0.1132617E 14 0.1132617E 14 0.1041179E 24 0.9909632E 13 0.9225367E 13 0.9225367E 13 0.9225367E 13 0.7306336E 13 0.5631387E 13 0.5631387E 13 0.5631387E 13 0.4664692E 13 0.4227126E 13 0.4227126E 13 0.4227126E 13 0.4227126E 13 0.4227126E 13 0.4277126E 13 0.4277126E 13 0.3644526E 13 0.3647536E 13 0.1736537E 12 0.2043766E 12 0.3853647E 12 0.3853647E 12 0.2834388E 12 0.246376E 12 0.26377E 12 0.26377E 12 0.126372E 12 0.126372E 12 0.126372E 12 0.126372E 12	F5 0-11666 # 3 # 14 0-10775 # 14 0-102916 p	130040   14	14
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17	0.3355950E-04	0.4685964E 32	0.4425795E 32	0.4181093E 32	0.7208747E 32	0.7005995E 32	0.6809515E 32	0.3431711E 33
18	D.3354760E-04	0.4892882E 32	0.4635192E 32	0.4392072E 32	0.7277400E 32	0.7078182E 32	0.688497DE 32	0.3516070F 35
19	0.3353550E-04	0.5093332E 32	0.4838202E 52	0.45968246 32	0.7338033E 32	0.71423B3E 32	0.69524782 32	0.3596125E 33
20	0.3352290E-04	0.5287285E 32	U.5034786E 52	0.4795290 32	0.739096°E 32	0.7198905E 32	0.7012339E 32	6.3671957E-33
21	0.3350990E-04	0.5474489E 32	U.5224695E 32	0.49872135 32	0.7436197E 32	0.7247736E 32	0.7064540= 52	0.3745487E 33
22	0.3349650E-04	0.5654/63E 32	0.5407744E 32	0.71724025 32	n.7473803E 32	U.7288953E 32	0.71091596 37	0.5510683635-
23	0,3348280E-04	0.5827869E 32	0.5583699E 32	0.>350615E 32	0.75g3798E 32	D.7322587E 52	G.7146204E 52	0.5873477E.33
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26	0.3343910E-04	0.63032>0F 32	0.6068018E 32	0.5842337E 32	0.7550c23E 32	0.7379735E 32	0.72136876 32	0.4035705E 35
27	0.3342380E-04	0.6446549E 32	0.6214424E 32	a.59914015 32	0.75511736 32	0.7384527E 32	0.72219422 32	C . 4681002F 35
-28	0.3340810E-04	2.6582120E 32	0.6353159E 32	0.6132880E 32	0.7545475E 32	0.7382465E 32	-0.7223344= 32-	
29	0.3339190E-04	0.6709964E 32	U.0484219E 32	1.6266761E 32	0.7533183E 32	0.7373799E 32	0.7218140= 32	C.41596C7E 35
30	0.3337540E-04	3.69298565 32	0.6607382E 32	0.63928216 32	0.7514291E 32	0.7358522E 32	0.72163226 32	6.419J919E 35-
31	0.33358606-04	0.6941743E 32	3 . 6722591E 32	C.6511003E 32	n.748898cE 32	0.73365146 32	0.7188065= 32	0.4218919E 35
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33	0.3332360E-04	0.7141799E 34	0-6929417E 32	J. 6723947E 32	0.74203106 32	0.7275290E 32	1.7133404E 52	C-4262417E 35
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35	0.3328700E+04	0.7309965E 32	0.7104507E 32	0.69053775 32	0.7328669E 32	0.71907024 32	p.7055638E 32	C.4289483E 35
36	0.33268306-04	0.7381951E 32	3.718C009E 32	0.6984123E 32	0.7274579E 32	0.7140101E 32	0.70C8373E 52	0.42969135 33
37	0.3324913E-04	0.7446125E 32	0.7247725E 32	0.7355122F 32	0.7215408E 32	0.7084447E 32	J.6956057c 32	C.430J494E 35
28	0.3322940E-04	0.7502549E 32	J.7307710E 32	0.7118423E 32	0.71515555 32	0.70239556 32	0.6898874E 32	0.4300106E 35
39	0.3320950E-04	0.7551014E 32	J.7359764E 32	G.7173832F 32	J.7J82502= 32	D.69>8592€ 32	U.6836791E 32	0.4296279E 33
·#0 -	0:3318910E-04	0.7591878E 32	J.7404231€ 52	0.7221678E 32	0.70096946 32	0.6888834E-32-		-0.4288659E-33-
41	0.3316840E-04	0.7625352E 32	J.7441024E 52	6.7261875E 32	0.69322862 32	0.6814739E 32	0.6699397E 32	0.4277437E 35
42	0.3314740E-04	0.76506438 32	0.7470245E 32	0.7294523E 32	0.6850810E 32	0.6736535E 32	0.6624369E 32	3.4262712E 33
43	0.3312590E-04	0.76689518 32	0.7492190E 32	0.7319907E 32	0.676566DE 32	0.6654612E 32	U,6543582E 32	0.424469gE 35
44	D.3310380E-04	0.7680203E 32	0.75070766 32	0.7338241E 32	0.6677141E 32	0.65692746 32	0,6463336E 32	0.4223527E-33
45	0.33081106-04	0.7684538E 32	J.7515042E 32	0.7349659E 32	0.6585475E 32	0.6480740# 32	0.6377849E 52	0.41993305 33
-46 -	-0-3305770E-04	0.7682202E 32	·0.7516327E 32	0.7354394F 32	0.6490961E- 32	9.6389397E- 32	- 8.6289415E-32-	0-4172261E-33
47	0.3303380E-04	0.7673156E 32	0.7510906E 32	0.7352422E 32	0.6393658E 32	0.6295035E 32	0.6198096E 32	3.4142328€ 35
48	0.330092CE-04	0.7657784E 32	0.7499123E 32	0.7344081E 32	0.62939386 32	0.6198293E 32	0.6104257E 32	0.4109748E-33
49	0.3298390E-04	0.7636231E 32	0.7481152E 52	0.7329541E 32	0.6192010E 32	0.60992895 32	U.6008105E 32	0.4074633E 35
50	0.3295800E-04	0.7608593E 32	0.7457078E 32	0.7308886E 32	0.6088006E 32	0.5998155E 32	0.5909773E 12	0.4037049E 35
51	0.3293140E-04	0.7575150E 32	0.7427176E 32	0.7282387E 32	0.5982205E 32	0.5895169E 32	0.58095356 32	0.399/162E 33
52 -	0,3290420E-04	0.7536002E 32	0.7391547E #2	0.725V143E 32	0.5874734E 32			- 0-3955040E-34-
53	0.3287620E-04	0.7491530E 32	0.7350564E 32	0.7212522E 32	0.5765930E 32	1.5684357E 32	0.5604062E 32	0.3910897E 35
54	0,3284760E-04	0.7441751E J2	U.7304247E 32	0.716954JE 32	0.5655843E 32	-0.5576917E 32	0.5499211E -32	0.3864751E 33-
55	0.3281820E-04	0.7387052E 32	0.7252975E 32	0.7121582E 32	0.5544796E 32	0.5468459E 32	0.5393286E 32	0.3816815E 35
56	0.3278810E-Q4	0.73275486 32	0.7196866E 32	0.706B755E 32	0.5432898E 32-	0.5359093E 32	#*358003AAE-95	-0-3767156E-35-

TABLE IV. COMPUTED NORMALIZED EMISSION COEFFICIENTS
IN 1 ATM NITROGEN AND AIR PLASMAS.\*\*

T	NITROG			AIR	, ,	
	BH△ <sub>1</sub>	BH△2	λ7468	BH△ <sub>1</sub>	BH△2	λ7468
°K	3.9A°	28A °	NI	3.9A°	28A °	NI
2000	1.0915*	3.70 <sup>16</sup>	4.11-41	3.14 <sup>08</sup>	1.0710	3.65-41
2400	1.9619	1.8820	4.62-34	7.9013	7.5814	$4.07^{-34}$
2800	3.56 <sup>22</sup>	$3.68^{20}$	4.94-29	9.56 <sup>17</sup>	9.89 <sup>18</sup>	4.30-29
3200	9.5824	1.0526	2.88 <sup>-25</sup>	1.11 <sup>21</sup>	1.23 <sup>22</sup>	2.47 <sup>-25</sup>
3600	$7.04^{26}$	8.3227	2.42 <sup>-22</sup>	$2.76^{23}$	$3.26^{24}$	$2.02^{-22}$
4000	$2.17^{28}$	$2.67^{29}$	5.25 <sup>-20</sup>	2.57 <sup>25</sup>	3.18 <sup>26</sup>	$4.27^{-20}$
4400	3.41 <sup>29</sup>	4.39	4.24-18	1.13 <sup>27</sup>	1.4528	3.43 <sup>-18</sup>
4800	$3.22^{30}$	4.3131	1.63-16	2.7028	3.62 <sup>29</sup>	1.32-16
5200	$2.01^{31}$	$2.78^{32}$	3.52 <sup>-15</sup>	3.92 <sup>29</sup>	5.43 <sup>30</sup>	2.83 <sup>-15</sup>
5600	8.92 <sup>31</sup>	$1.27^{33}$	4.79-14	$3.77^{30}$	5.38 <sup>31</sup>	$3.84^{-14}$
6000	2.96 <sup>32</sup>	4.35	4.44-13	$2.57^{31}$	$3.77^{32}$	3.57 <sup>-13</sup>
6400	7.53 <sup>32</sup>	1.1434	2.96-12	$1.24^{32}$	1.82 <sup>33</sup>	2.37 <sup>-12</sup>
6800	1.53 <sup>23</sup>	2.36 <sup>34</sup>	1.47-11	4.34 <sup>32</sup>	6.68 <sup>33</sup>	1.17-11
7200	$2.48^{33}$	3.89 <sup>34</sup>	5.66 <sup>-11</sup>	1.04 <sup>33</sup>	1.6134	4.48-11
7600	3.32 <sup>33</sup>	$5.33^{34}$	1.74-10	1.77	2.83 <sup>34</sup>	1.37-10
8000	3.88 <sup>33</sup>	6.34 <sup>34</sup>	4.46-10	2.2433	3.80 <sup>34</sup>	3.51 <sup>-10</sup>
8400	4.16 <sup>33</sup>	6.9034	1.00-9	$2.64^{33}$	4.3934	7.87-10
8800	4.23 <sup>35</sup>	7.13 <sup>34</sup>	2.04-9	2.77	4.6834	1.60-9
9200	4.17 <sup>33</sup>	$7.14^{34}$	3.83 <sup>-9</sup>	2.79 <sup>33</sup>	4.7834	3.01 <sup>-9</sup>
9600	4.03 <sup>33</sup>	7.0134	6.75 <sup>-9</sup>	$2.73^{33}$	4.75	5.29 <sup>-9</sup>
10000	3.82 <sup>33</sup>	6.75 <sup>34</sup>	1.12-8	2.63 <sup>33</sup>	4.63 <sup>34</sup>	8.79 <sup>-9</sup>

<sup>\*</sup> Superscript means power of 10.

<sup>\*\*</sup> Similar data for  $R_6$ ,  $R_{22}$  and  $R_{38}$  components are given in Tables I and II.

TABLE V. SUMMARY OF DATA

RUN #	TRACE #	TYPE	λ	ENNHANCE WIDTH		EXIT SLIT	SPEC	z	MAG	JET OPEN	QUENCH	H ave	T <sub>ave</sub>	SPECTRAL TEMP. RANGE
			(Å)	(IN.)	(IN.	ا .ه. ا		(IN.)		<u></u>		(BTU/1b)	( °K)	( ok)
1	6-69-18	В–Н	3914	.002	.161	4.0	LS	0.3	+5	N0	YES	4227	5750	7900-5400
2	6-72-1	BH	3914	.002	.161	3.81	LS	0.3	+5.	NO	YES	4196	5700	7800-5400
3	6-72-7	ATOM	7468	.002	.161	3.81	LS	0.3	+5	NO	YES	4196	5700	7800-6900
4	6-72-13	R-38	3323	.002	.161	1.1	LS	0.3	+5	NO	YES	4196	5700	7400-5500
5	6-72-19	R <b>≔16</b> ·	3895	.002	.161 ·	1.1	LS	0.3	+5	NO	YES	4196	5700	6700-5200
6	6-72-23	<b>R-6</b>	3906	.002	.161	1.1	LS	0.3	+5	NO	YES	3849	5500	7800-5400
7	6-73-1	R-6	3906	.002	.161	0.9	LS	0.3	+5	NO	YES	<b>392</b> 5	5600	7800-5400
8	6-73-5	R-16	3895	.002	.161	1.3	LS	0.3	+5	NO	YES	3925	5600	6700-5200
9	6-73-12	R-38	3323	.002	.161	1.3	LS	0.3	+5	NO	YES	3925	5600	7400-5500
10	6-73-18	CONT	5600	.002	.161	3.71	LS	0.3	+5	NO	YES	3925	5600	8800-8000
11	6-74-1	ATOM	7468	.002	.161	3.71	LS	0.3	+5	NO	YES	5132	6000	9300-6700
12	6-74-2	В–Н	3914	.002	.031	4.53	SS	0.3	+5	N.O	YES	5132	6000	9300-5200
13	6-74-7	ATOM	7468	.002	.161	3.71	LS	0.3	+5	NO	YES	5713	6150	9600-6600
14	6-74-8	В-Н	3914	.002	.031	4.53	SS	0.3	+5	NO	YES	5713	6150	9400-5300
15	6-74-19	ATOM	7468	.002	.161	3.71	LS	0.3	+5	NO	YES	6979	6450	10300-6900
16	6-74-20	В–Н	3914	.002	.031	4.53	SS	0.3	+5	NO	YES	6979	6450	10100-5500
17	6-74-25	R-16	3895	.002	.161	0.82	LS	0.3	+5	NO	YES	6041	6250	10000-5800
18	6-75-1	R-6 '	3906	.002	.161	0.82	LS	0.3	+5	NO	YES	6041	6250	10600-6000
19	6-75-7	R-38	3323	.002	.161	0.82	LS	0.3	+5	NO	YES	6041	6250	11000-5500
20	6-75-29	ATOM	7468	.002	.161	3.67	LS	0.3	+5	NO	YES	6041	6250	10800-8200
21	6-78-7	ATOM	7468	.002	.161	3.86	LS	0.3	+5	NO	YES	4707	5900	7500-5900
22	6-78-8	ВН	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	4707	5900	7200-5100
23	6-78-13	ATOM	7468	.002	.161	3.86	LS	0.3	+5	NO	YES	3691	5500	7200-5800
24	6-78-14	В–Н	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	3691	5500	6800-5000
25	6-78-19	ATOM	7468	.002	.161	3.86	LS	0.3	+5	NO	YES	3117	5150	6700-5500

AEDC-TR-70-239

TABLE V (Continued)

Run #	TRACE #	TYPE	λ Å	ENTRANCE WIDTH (IN.)	SLIT HEIGHT (IN.)	EXIT SLIT (Å)	SPEC	Z (IN.)	MAG	JET OPEN	QUENCH	H <sub>ave</sub>	Tave	SPECTRAL TEMP. RANGE (°K)
26	6-78-20	В–Н	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	3117	5150	6300-4600
27	6-78-29	R-22	3886	.002	.161	0.71	LS	0.3	+5	NO	YES	5791	6200	10000-5500
28	6-78-30	В-Н	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	5791	6200	9100-5500
29	6-79-5	R-22	3886	.002	.161	0.71	LS	0.3	+5	NO	YES	5187	6060	8000-5500
30	6-79-6	В-Н	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	5187	6060	8000-5500
31	6-79-11	R-22	3886	.002	.161	0.71	LS	0.3	+5	NO	YES	4543	5850	7600-4900
<b>32</b>	6-79-12	В-Н	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	4543	5850	7600-4900
33	6-79-17	R-22	3886	.002	.161	0.71	LS	0.3	+5	NO	YES	3691	5500	6700-5000
34	6-79-18	В-Н	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	3691	5500	6700-5000
35	6-69-23	R-22	3886	.002	.161	0.71	LS	0.3	+5	NO	YES	2804	4900	6400-4700
36	6-79-24	В-Н	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	2804	4900	6400-4700
37	6-79-29	R-22	3886	.002	.161	0.71	LS	0.3	+5	NO	YES	2093	<b>3900</b>	6100-4700
38	6-79-30	B-H	3914	.002	.031	4.26	SS	0.3	+5	NO	YES	2093	<b>3900</b>	6100-4700
39	6-81-19	<b>ATOM</b>	7468	.002	.031	12.6	LS	0.05	+5	-	_	-	-	26000-8000
40	6-82-7	R-38	3323	.002	.161	0.8	LS	0.3	+5	NO	YES	5467	6100	<b>7500–</b> 5000
41	6-82-8	B–H	3914	.002	.031	4.53	SS	0.3	+5	NO	YES	5467	6100	7500-5000
42	6-82-13	R-38	3323	.002	.161	0.8	LS	0.3	+5	NO	YES	<b>3100</b>	5100	6600-4900
43	6-82-14	В–Н	3914	.002	.031	4.53	SS	0.3	+5	NO	YES	3100	<b>5100</b>	6600 <b>–4</b> 900
44	6-83-1	B-H	3914	.002	.031	4.53	SS	0.3	+5	NO	YES	2344	4300	6100-5000
45	6-83-5	В-Н	3914	.002	.161	4.53	SS	0.3	+5	NO	YES	1396	2600	5100-4500

TABLE V (Continued)

RUN #	TRACE #	ТҮРЕ	λ	ENTRANCE WIDTH	SLIT HEIGHT	EXIT SLIT	SPEC	Z	MAG	JET OPEN	QUENCH	Have	T <sub>ave</sub>	SPECTRAL TEMP. RANGE
			(Å)	(IN.)	(IN.)	(Å)		(IN.)				(BTU/lb)	( ok)	( oK)
46	6-84-1	т т	7014	0.000	0 161	L 57	OC.	0.7		170	3750	4500	0000	1000 1000
		В.Н	3914	0.002	0.161	4.53	SS	0.3	+5	NO	YES	1508	2900	4900-4000
47	6-87-1	В.Н	3914	0.002	0.031	4.53	SS	0.3	<u>_4</u>	NO	YES	2428	4300	5820-4620
48	6-87-5	В.Н	3914	0.002	0.031	4.53	SS	0.3		NO	YES	2428	2100	4500-3825
49	6-87-9	B.H	3914	0.002	0.031	4.53	SS	0.3	+5	NO	YES	3190	5170-	6500-4700
50	6-88-1	B.H	3914	0.002	0.0635	-	<b>LS</b>	0.3	+5	NO	YES	<b>3190</b>	5170	6500-4700
51	6-88-2	B.H	3914	0.002	0.020	28.6	SS	0.3	+5	NO	YES	<b>3190</b>	5170	6550-4790
52	6-88-5	Cont	<b>3920</b>	0.002	0.020	28.6	SS	0.3	+5	NO	YES	<b>3190</b>	5170	6550-4790
53	6-88-10	B.H	3914	0.002	0.0635	4.07	ES	0.3	+5	NO	YES	1625	3120	5325-4225
54	6-88-11	B.H	3914	0.002	0.031	28.6	SS	0.3	+5	NO	YES	1625	3120	5325-4225
55	6-88-14	${f Cont}$	<b>3920</b>	0.002	0.031	28,6	SS	0.3	+5	NO	YES	1625	3120	5 <b>325-422</b> 5 .
56	6-89-7	B.H	3914	0.002	0.161	4.07	LS	0.3	+5	NO	YES	1860	3580	5410-4250
<b>57</b>	6-89-9	B.H	3914	0.002	0.161	28.6	SS	0.3	+5	NO	YES	1860	3580	5410-4250
58	6-89-19	B.H	3914	0.002	0.161	4.07	ES	0.3	+5	NO	YES	1720	3320	5300-4325
59	6-89-21	B.H	3914	0.002	0.161	28.6	SS	0.3	+5	NO	YES	1720	3320	5300-4325
60	6-91-2	B.H	3914	0.002	0.161	4.59	SS	0.3	+5	NO	YES	4615	5850	7500-5200
61	6-91-6	B.H	3914	0.002	0.161	4.59	SS	0.3	+5	NO	YES	3131	5120	6370-4900
62	6-92-2	в.н	3914	0.002	0.161	4.59	SS	0.3	+5	NO	YES	3370	5280	6800-4800
63	6-93-1	Cont	5575	0.002	0.161	6.0	LS	0.3	+5	YES	YES	4502	5850	8600-5370
64	6-93-2	B.H	3914	0.002	0.161	4.59	SS	0.3	+5	YES	YES	4502	5850	8600-5370
65	6-93-3	Cont	<b>3920</b>	0.002	0.161	4.59	SS	0.3	+5	YES	YES	4502	5850	8600-5370
66	6-93-6	Cont	3920	0.002	0.040	28.6	SS	1.22	_4	YES	YES	2739	4800	4880-4080
67	6-93-7	B.H	3914	0.002	0.040	28.6	SS	1.22	_4	YES	YES	2739	4800	4880-4080
68	6-93-8	Cont	5600	0.002	0.040	28.6	SS	1.22	_4	YES	YES	2739	4800	4880-4080
69	6-93-12	в.н	3914	0.002	0.040	4.06	ĽS	1,22	_4	YES	YES	1456	2800	4305-3710

TABLE V (Continued)

RUN #	TRACE #	TYPE	λ	ENTRANCE WIDTH	SLIT HEIGHT	EXIT SLIT	SPEC	Z	MAG	JET OPEN	QUENCH	Have	Tave	SPECTRAL TEMP. RANGE
			(Å)	(IN.)	(IN.)	(A)		(IN.)				BTU/1 b	(°K)	( °K)
70	6-93-13	Cont	5600	0.002	0.040	86	SS	1.22	_4	YES	YES	1456	2800	4305-3710
71	6-93-16	Cont	5600	0.002	0.040	86	SS	1,22	-4	YES	YES	2087	3900	5250-4280
72	6-93-17	Cont	<b>5600</b>	0.002	0.040	86	SS	1.22	_4	YES	YES	1917	<b>3</b> 650	5180-3950
73	6-93-18	Cont	5600	0.002	0.040	86	SS	1.22	_4	YES	YES	1773	3400	5140-4020
74	6-93-19	${f Cont}$	5600	0.002	0.040	86	SS	1.22	_4	YES	YES	1542	2950	4850-4040
<b>7</b> 5	6-93-20	B.H	3914	0.002	0.040	4.06	LS	1.22	4	YES	YES	1542	2950	4850-4040
76	6-94-1	Cont	5600	0.002	0.161	86	SS	1.22	+5	YES	YES	2781	4850	4910-4120
77	6-94-2	Cont	5600	0.002	0.161	86	SS	1.22	+5	YES	YES	2363	4350	4910-4120
78	6-94-3	Cont	5600	0.002	0.161	86	SS	1.22	+5	YES	YES	2053	3850	4910-4120
79	6-94-4	B.H	3914	0.002	0.161	4.06	LS	1.22	+5	YES	YES	2781	4850	4910-4120
80	6-94-8	B.H	3914	0.020	0.020	4.06	LS	1.22	_4	YES	YES	4728	5880	5960-4500
81	6-94-9	B.H	3914	0.020	0.020	4.06	LS	1.22	_4	YES	YES	2079	<b>3900</b>	4140-3660
82	6-94-9 <b>a</b>	${f Cont}$	<b>3920</b>	0.020	0.020	4.06	LS	1.22	_4	YES	YES	2079	3900	4140-3660
83	6-94-11	B.H	3914	0.020	0.020	4.06	LS	1.72	_4	YES	YES	4728	5880	5220-4300
84	6-94-12	Cont	3914	0.020	0.020	4.06	LS	1.72	_4	YES	YES	1678	3210	4100-3450
85	6-94-15	B.H	3914	0.020	0.020	4.06	LS	1.72	_4	YES	NO	4728	5880	4910-4080
86	6-94-15a	Cont	<b>3920</b>	0.020	0.020	4.06	LS	1.72	4	YES	NO	4728	5880	4910-4080
87	6-94-16	B.H	3914	0.020	0.020	4.06	LS	1.72	_4	YES	NO	3712	3210	4245-3820
88	6-94-16a	Cont	3920	0.020	0.020	4.06	LS	1.72	_4	YES	NO	3712	3210	4245-3820
89	6-95-1	B.H	3914	0.020	0.020	28.6	SS	1.72	_4	YES	NO	5243	6050	5220-4520
90	6-95-2	Cont	3920	0.020	0.020	28.6	SS	1.72	_4	YES	NO	5243	6050	5220-4520
91 -	6-95-3	Cont	5600	0.020	0.020	28.6	SS	1.72	_4	YES	NO	5243	6050	5220-4520
92	6-95-4	B.H	3914	0.020	0.020	28.6	SS	1.72	_4	YES	NO	4612	5850	4950-4260
93	6-95-5	Cont	3920	0.020	0.020	28.6	SS	1.72	_4	YES	NO	4612	5850	4950-4260

TABLE V (Continued)

HUN #	TRACE #	TYPE	λ	ENTRANCE WIDTH	SLIT HEIGHT	EXIT SLIT	SPEC	Z	MAG	JET OPEN	QUENCH	H <b>av</b> e	T <sub>ave</sub>	SPECTRAL TEMP. RANGE
			(Å)	(IN.)	(IN.)	(Å)		(IN.)				вту⁄1ь	( °K)	( oK)
94	6-95-6	Cont	5600	0.020	0.020	28.6	SS	1.72	_4	YES	NO	4612	5850	4950-4260
95	6-95-7	B.H	3914	0.020	0.020	28.6	SS	1.72	_4	YES	NO	4117	5650	4740-4120
96	6-95-8	Cont	3920	0.020	0.020	28.6	SS	1.72	_4	YES	NO	4117	5650	4740-4120
97	6-95-9	Cont	5600	0.020	0.020	28.6	SS	1.72	_4	YES	NO	4117	5650	4740-4120
98	6-95-10	B.H	3914	0.020	0.020	28.6	SS	1.72	_4	YES	NO	3470	5350	4560-4075
99	6-95-11	Cont	3920	0.020	0.020	28.6	SS	1.72	<u>1</u>	YES	NO	3470	5350	4560-4075
100	6-95-12	Cont	5600	0.020	0.020	28.6	SS	1.72	_4	YES	NO	3470	5350	4560-4075
101	6-95-13	в.н	3914	0.020	0.020	28.6	SS	1.72	_4	YES	NO	3093	5110	4415-3905
102	6-95-14	Cont	<b>3920</b>	0.020	0.020	28.6	SS	1.72	_4	YES	NO	3093	5110	4415-3905
103	6-95-15	Cont	5600	0.020	0.020	28.6	SS	1.72	_4	YES	NO	3093	5110	4415-3905
104	6-95-25	B.H	3914	0.020	0.020	28.6	SS	1.72	-4	YES	NO	3093	<b>5110</b>	4280-3760
105	6-95-25a	Cont	3920	0.020	0.020	28.6	SS	1.72	_4	YES	NO	3093	5110	4280-3760
<b>10</b> 6	6-95-26	${f Cont}$	5600	0.020	0.020	28.6	SS	1.72	-4	YES	NO	3093	5110	4280 <b>–37</b> 60
107	6-96-1	Cont	<b>3920</b>	0.020	0.020	28.6	SS	1.72	_4	YES	NO	4894	5950	5150-4050
108	6-96-2	Cont	<b>3920</b>	0.020	0.020	28.6	SS	2.37	-4	YES	NO	4894	5950	4720-3830
109	6-96-3	Cont	3920	0.020	0.020	28.6	SS	2.37	-4	YES	NO	2368	4350	4040-3200

TABLE V (Continued)

RUN #	TRACE #	ТҮРЕ	λ (Å)	ENTRANCE WIDTH (IN.)	SLIT HEIGHT (IN.)	EXIT SLIT (A)	SPEC	Z (IN.)	H <sub>ave</sub> (BTU/1b)	Tave	SPECTRAL TEMP. RANGE (°K)	FLOW (SCFH)
110	6-97-1	В–Н	3914	.002	.16	4.07	LS	0			7200-5600	AIR 30
111	6-97-3	CONT	3920	.002	.16	4.07	LS	0			7200-5600	AIR 30
112	6-97-4	ATOM	7469	.002	.16	4.07	LS	0			6600-5450	AIR 30
113	6-97-5	CONT	7475	.002	.16	4.07	1.S	0			6600-5450	AIR 30
114	6-97-6	B-H	3914	.002	.06	4.07	LS	0			6300-5400	AIR 30
115	6-97-8	CONT	3920	.002	.06	4.07	$\mathbf{L}\mathbf{S}$	0			6300-5400	AIR 30
116	6-97-9	ATOM	7469	.002	•06	4.07	LS	0			6100-5800	AIR 30
117	6-97-10	CONT	7475	.002	.06	4.07	${f LS}$	0			6100-5800	AIR 30
118	6-97-15	В-Н	3914	.002	.06	4.07	LS	0			8500-5500	N <sub>2</sub> 30
119	6 <b>-</b> 99-1	B–II	3914	.020	.020	28	SS	0.3	4150	4800	7000-5900	$N_2 + 0_2 111$
120	6 <b>–99–</b> 2	CONT	3920	.020	.020	28	SS	0.3	4150	4800	7000-5900	$N_2 + 0_2 111$
121	6-99-3	B-II	3914	.020	.020	28	SS	1.09	4150	4800	6100-5450	$N_2 + 0_2 \setminus 111$
122	6-99-4	CONT	3920	.020	.020	28	SS	1.09	4150	4800	6100-5450	$N_2 + 0_2  111$ $N_2 + 0_2  111$
123	6-99-5	B-II	3914	.020	.020	28	SS	1.26	4150	4800	<b>5900-4850</b>	$N_2^2 + 0_2^2 111$
124	6-99-6	CONT	3920	.020	.020	28	SS	1.26	4150	4800	5900-4850	$N_2 + 0_2 111$
125	6-99-7	B-H	3914	.020	.020	28	SS	1.37	4150	4800	5700-4800	$N_2^2 + 0_2^2$ 111
126	6-99-7a	CONT	3920	.020	.020	28	SS	1.37	4150	4800	5700-4800	$N_2^2 + 0_2^2$ 111
127	6-99-16	CONT	3920	.020	.020	28	SS	1.37	3000	3900	5500-3500	$N_2^2 + 0_2^-$ 141
128	6-99-17	CONT	3920	.020	.020	28	SS	1.69	3000	3900	5200-3300	$N_2 + 0_2 141$
129	6-99-18	CONT	3920	.020	.020	28	SS	2.99	3000	3900	4900-3100	$N_2^2 + 0_2^2$ 141
130	6-99-19	CONT	3920	.020	.020	28	SS	3.24	3000	3900	4800-3000	$N_2^2 + 0_2^2$ 141
131	6-99-20	CONT	3920	.020	.020	28	SS	2.19	3000	3900	5600-3600	$N_0^2 + 0_0^2$ 141
132	6-100-1	В–Н	3914	.020	.020	6	LS	0.3	5080	6000		$N_2^2 + 0_2^2 141$ $N_2 88$
133	6-100-2	B–II	3914	.020	.020	6	LS	0.3	3771	4500	6750-5100	$N_2^2 + 0_2 111$
134	6-100-3	CONT	3920	.020	.020	6	LS	0.3	3771	4500	6750-5100	$N_2^2 + 0_2^2$ 111
135	6-100-4	ATOM	7469	.020	.020	6	LS	0.3	3771	4500	7000-5800	$N_2^2 + 0_2^2$ 111
136	6-100-5	ATOM	7469	.020	.020	6	LS	0.6	3853	4550	6700-5500	$N_2^2 + 0_2^2$ 111
137	6-100-6	В-Н	3914	.020	.020	6	LS	0.6	3895	4550	6700-5100	$N_{2}^{2}+0_{2}^{2}$ 111
138	6-100-7	CONT	3920	.020	.020	6	LS	0.6	3895	4550	6700-5100	$N_2^{10}$ 111

TABLE V (Continued)

RUN #	TRACE 1	TYPE	λ (Å)	ENTRANCE WIDTH (IN.)	SLIT HEIGHT (IN.)	EXIT SLIT (A)	SPEC	Z (IN.)	Have (BTU/1b)	Tave (°K)	SPECTRAL TEMP. RANGE (°K)	FLOW (SCFH)
139	6-100-8	В-Н	3914	.020	.020	6	ıs	0.9	3895	4550	6200-5100	N <sub>2</sub> +0 <sub>2</sub> 111
140	-	CONT	<b>3920</b>	.020	.020	6	LS	0.9	3895	4550	6200-5100	$N_{0}^{-}+0_{0}^{-}$ 111
141	6 <b>–</b> 100–10 <i>A</i>	ATOM	7469	.020	.020	6	LS	0.9	3895	4550	6250-5450	$N_2 + 0_2 = 111$
142		B–II	3914	.020	.020	6	1.8	1.20	<b>389</b> 5	4550	5700-5050	$N_2^2 + 0_2^2$ 111 $N_2^2 + 0_2^2$ 111
143	6-100-12 (	-	<b>3920</b>	.020	.020	6	LS	1.20	3895	4550	5700-5050	$N_2 + 0_2 111$
144	_	B-H	3914	.020	.020	6	ĹS	1.37	<b>389</b> 5	4550	5400 <del></del> 4500 ¯	$N_2^{+0}_2$ 111
145	6-100-14 (	CONT	<b>3920</b>	.020	.020	6	1.8	1.37	3895	4550	5400-4500	$N_2^2 + 0_2^2$ 111
146	_	B-H	3914	.020	.020	6	IS	1.50	3895	4550	4900-4500	$N_2^2 + 0_2^2$ 111
147	6-100-16	CONT	<b>3920</b>	.020	.020	6	18	1.50	3742	4500	4900-4500	$N_2^2 + 0_2^2$ 111
148	6-100-17	CONT	<b>3920</b>	.020	.020	6	LS	1.80	3742	4500	5000-3000	$N_2^2 + 0_2^2$ 111
149	6-100-18	CONT	3920	.020	.020	6	LS	2.10	3742	4500	4900-3000	$N_{2}^{2}+0_{2}^{2}$ 111
150	6-100-19	CONT	3920	.020	.020	6	LS	2.40	3742	4500	5000-3000	$N_0 + 0_0 = 111$
151	6-100-20	CONT	<b>3920</b>	.020	.020	6	LS	2.70	3742	4500	4800-3000	$N_2^2 + 0_2^2$ 111
152	6-102-1	В-П	3914	.020	.020	4	LS	0.3	2713	3700	6400-5000	$N_2^2 + 0_2^2$ 141
153	6-102-2	CONT	<b>3920</b>	.020	.020	4	TS	0.3	2713	3700	6400-5000	$N_2^2 + 0_2^2$ 141
154	6-102 <b>-</b> 3	<b>B</b> –H	3914	.020	.020	4	LS	0.6	<b>2713</b>	3700	6200-5200	$N_2^2 + 0_2^2$ 141
155	6-102-4	CONT	3920	.020	.020	4	IS	0.6	2713	3700	<b>5950-5300</b>	$N_2^2 + 0_2^2$ 141
156	6-102-5	В–Н	3914	.020	.020	4	LS	0.9	2713	3700	5950-5300	$N_2^2 + 0_2^2$ 141
157	6-102-6	CONT	3920	.020	.020	4	LS	0.9	2713	3700	5900-5100	$N_2^2 + 0_2^2$ 141
158	6-102-7	B-H	3914	.020	.020	4	IS	1.2	2713	3700	5900-5100	$N_2^2 + 0_2^2$ 141
159	_	CONT	3920	.020	.020	4	1.5	1.2	2713	3700	5450-4350	$N_2^2 + 0_2^2$ 141
160		CONT	3920	.020	.020	4	LS	1.5	2713	3700	5200-3350	$N_2^2 + 0_2^2$ 141
161	6-102-10		3920	.020	.020	4	LS	1.8	2713	3700	5000-3300	$N_0^2 + 0_0^2$ 141
162	6-102-11		<b>3920</b>	.020	.020	4	IS	2.1	2713	3700	4700-3300	$N_2^2 + 0_2 141$ $N_2^2 + 0_2 141$
163	6-102-12		3920	.020	.020	4	15	2.4	2713	3700	4350-3300	$N_2^2 + 0_2^2$ 141
164	6-102-13		3920	.020	.020	4	LS	2.7	2713	3700	4100-3100	$N_2^{2+0} = 141$

## TABLE V (Continued)

RUN #	TRACE #	TYPE	λ (Å)	ENTRANCE WIDTH (IN.)	SLIT HEIGHT (IN.)	EXIT SLIT (A)	SPEC	Z (IN.)	H ave (BTU/1b)	T ave (°K)	SPECTRAL TEMP. RANGE (°K)	FLOW (SCFH)
165	6-102-14	CONT	3920	.020	.020	4	LS	3.0	2713	3700	3800–3000	N <sub>2</sub> +0 <sub>2</sub> 141

NOTES: 1.

- Jet was open for runs 110-165.
- Magnification was 4 for jet, 7 for RF.
- Quench was removed for runs 110-165.
- 4. Runs 110-118 are RF, runs 119-165 are jet.

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Using as a source a dc subsonic plasma jet operating in nitrogen and in nitrogen-oxygen mixtures at atmospheric pressure, emission coefficients of the  $N_2(2+)(0,0)$   $\lambda 3371$  neutral molecule band,  $N_2(1-)(0,0)$   $\lambda 3914$  ionized molecular band,  $\lambda 7468$  NI atomic line, and the electron continuum have been measured over the temperature range of 3800 to  $10000^{\circ}$ K. The emission coefficients of the discrete radiation, calibrated on an absolute scale, were used to calibrate the simultaneously measured electron continuum over the temperature range. Approximate analytical treatments were used to extrapolate the calibrated continuum curves to lower temperatures where discrete radiations cannot be observed. The experimental results show considerably higher continuum emission coefficients at low temperature than can be accounted for by any existing theoretical treatments.

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